A National Program of Research for

WATER AND WATERSHEDS

Prepared by

A JOINT TASK FORCE OF THE
U. S. DEPARTMENT OF AGRICULTURE
AND THE STATE UNIVERSITIES
AND LAND GRANT COLLEGES

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FOREWORD

The United States Department of Agriculture and State Agricultural Experiment Stations are continuing comprehensive planning of research. This report is a part of this joint research planning and was prepared under recommendation 2 (page 204, paragraph 3) of the National Program of Research for Agriculture.

The task force which developed the report was requested to express their collective judgment as individual scientists and research administrators in regard to the research questions that need to be answered, the evaluation of present research efforts, and changes in research programs to meet present and future needs. The task force was asked to use the National Program of Research for Agriculture as a basis for their recommendation. However, in recognition of changing research needs it was anticipated that the task force recommendations might deviate from the specific plans of the National Program. These deviations are identified in the report along with appropriate reasons for change.

The report represents a valuable contribution to research plans for agriculture. It will be utilized by the Department and the State Agricultural Experiment Stations in developing their research programs. It should not be regarded as a request for the appropriation of funds or as a proposed rate at which funds will be requested to implement the research program.

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This report has been prepared in limited numbers. Persons having a special interest in the development of public research and related programs may request copies from the Research Program Development and Evaluation Staff, Room 318-E Administration Bldg., USDA, Washington, D.C. 20250.

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TABLE OF CONTENTS

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INTRODUCTION

Water is an indispensable resource that permeates every aspect of society, affects every man, woman, and child. Many have always taken for granted its abundant availability, in quantity as well as quality. Others, less fortunate, have learned to respect its value and the need for sound and conservative management of the supply. Many have suffered the devastation of floods and experienced the costly burden of measures for flood protection.

In recent years, a clear recognition has developed among the general public, reflected in numerous governmental actions, of the limitations of the available water supply to meet the many needs of man. This recognition of the need for skillful management and for a rational basis of allocation has focused renewed attention on the need for a better and more detailed understanding, and hence, research problems dealing with water.

The charge of the present Task Force is the evaluation of research needs in water related to agriculture. Water is absolutely vital to agriculture. Further, agriculture assumes a most important role in the total water picture. Over 70 percent of the total annual precipitation that falls on the United States is withdrawn in evapotranspiration. About 25 percent of the continental precipitation is evapotranspired from productive agricultural land. In the 17 Western States, some 80 percent of water withdrawal is for irrigation. Thus, it is obvious that, as the largest consumptive user of water, agriculture is very important to the water economy.

Equally significant is the interface between urban and agricultural interests that revolves around water. Development of rural water resources permits recreational uses by urban and rural residents alike, and may affect urban expansion. Decisions on optimum use of available water resources must strike a balance between a variety of interests that encompass all segments of the population. Information gained from research in agriculture can have important application in urban settings.

In 1967, the Secretary of Agriculture spelled out the missions of agriculture in a series of speeches entitled, *Agriculture/2000*. To what extent does research on water and watersheds contribute to these broad missions?

The management of water on agricultural lands greatly affects agricultural production; irrigation, agricultural drainage and control of water erosion are obvious examples. As such, water management research contributes its share to the mission designated *Income and Abundance*. At least as important, however, is its relation to the programs for *Communities for Tomorrow* and *Resources in Action*. Research on watershed development should improve our ability to make the best possible use of the total land and water resources to meet the many faceted needs of rural society, including agricultural pro-

duction conservation of resources, reduction of flood damage, enhancing environmental quality, recreation, and tranquility through preservation or creation of natural beauty. Such resource development could be a major factor in enhanced use of the countryside to relieve the ugly and increasing pressures on our cities. Similarly, as stressed by the White House Panel on World Food Supply, the efforts to make less developed countries more nearly self-sufficient in food production will depend heavily on careful development and use of water resources using technologies which as yet are only partially developed, or unknown. Thus, water research has an important contribution to make to *Growing Nations, New Markets*.

In short, water research contributes significantly to every major goal of agriculture. Whereas the subject is classified for good and practical reasons in only a few categories and Research Problem Areas (RPA's), its effects are felt in many other areas of activity. There exists an urgent need to put to use our land and water resources effectively for the greatest benefit of man. Much can be accomplished by applying the know-how now at hand--far more through the fruits of research.

Historically, water from public development projects has been provided to farmers at relatively low cost, less than the total cost of developing the resource. With the growth of population, industrial development, and unused demand for goods and services of all kinds, competition for much of our water supplies by uses outside of agriculture has increased. This competition can be expected to increase intensively in the future and in other regions in addition to the West. Some analyses have shown lower rates of economic productivity for water in agriculture than in industrial uses.

In the interest of the welfare of both the agricultural industry and society as a whole, the need to increase the efficiency of water use in agriculture is obvious. This need is not restricted to particular water supplies which are now the object of competition. New points of competition will develop; in the meantime, the increasing costs of irrigating even where no competition exists emphasize the importance of lowering the quantities of water required for unit of output.

Many uses of water are mutually incompatible. Nowhere is this more evident than in the area of water quality. The use of water as a coolant tends to reduce its suitability for fish; nitrates may enhance the quality of irrigation water, but make it unsuited for human consumption. Whereas there is no question that agriculture affects water quality, quantitative data as to the specific effects are generally lacking. Such information is sorely needed to devise improved management techniques to reduce adverse effects, as well as to avoid the establishment of unworkable or unnecessarily punitive standards and regulations based on assumptions rather than facts.

Besides a responsibility to develop means for conserving water by more efficient use and by enhancing or maintaining quality, agriculture also has an opportunity to develop new technology for increasing the water supply

available for beneficial use. Watershed management for increasing water yield and technology for increasing ground-water recharge are examples of areas where the potential for improvement is great indeed. As the largest single consumer of water by far, even a small percentage improvement in present efficiency could have far-reaching effects.

Members of the Task Force note that, in recent years, there have been completed a number of detailed studies that are closely related to the question of water research. In particular the Committee on Water Resources Research (COWRR) of the Federal Council for Science and Technology has made an exhaustive and extended study of needs in this area, with recommendations for projected programs needs updated annually since 1966. Research programs have not kept pace with needs recognized by COWRR. Similarly, Senate Document 59, 86th Congress, *Facility Needs for Soil and Water Conservation Research*, reported the results of an extensive study of research needs carried out at the request of the Senate.

It is recognized that many problems in water resource development and water management research have important aspects of a physical or biological nature as well as socioeconomic aspects. It is considered of paramount importance that the research program recognize this dual aspect of the problems and, more effectively than in the past, be organized along interdisciplinary lines. Where possible, social scientists and physical scientists must work together towards solutions of problems couched in terms of a practical and attainable mission. The rate of progress from research can be enhanced considerably by a recognition of this fact, translated into active cooperative endeavors.

The Research Program Development and Evaluation Staff, USDA, considered that the subject matter, water and watersheds, was classified in *A National Program of Research for Agriculture* (herein referred to as the *Long Range Study* (LRS) under RPA's 105, 106, 107, and 108. The Task Force acknowledges a close relationship between these RPA's and its mission, but also included RPA 103, part of RPA 901, and some subject material that could not be classified from a reading of the Long Range Study.

The Task Force, after developing the 15 missions, attempted to determine the current program (1966) in each of these missions and then make its projections on the basis of needs. These estimates are summarized in Table 1. Attention is called to the projections for Chapter 13. As pointed out above, it was considered important to recognize the need for close cooperative work among social and physical scientists. Hence, allowance was made under each mission for the inclusion of some work by social scientists.

Whereas a direct comparison with the LRS inventory and projections is both impossible and of limited meaning, Table 2 was prepared to show the approximate relationship between the LRS and Task Force projections. The entries for Chapter 12 are an estimate of that portion of the projections by the Task Force on the Quality of the Environment related to water, excluding the subjects sediment and salinity. The double entry of Chapter 3 in Table 2

Table 1. Task Force Scientific Man-Year (SMY) estimates and projections

Subject	SMY Estimates 1966	1972	1977	RPA
1. Conserving water during storage and conveyance	40	60	80	105
2. Replenishment of ground water	30	65	125	105
3. Conserving soil water and reducing wind erosion	60	87	127	105, 107
4. Increasing and regulating streamflow	94	220	350	107
5. Improving water control and measurement structures	10	15	30	107
6. Increasing efficiency of irrigation water use	43	90	140	106
7. Removing excess water from soils	30	60	90	106
8. Managing wetlands	6	25	40	105
9. Increasing efficiency of salinity control and management	26	50	75	103
10. Optimizing water use by plants	25	55	90	105
11. Controlling water erosion and sediment	90	205	330	107
12. Maintaining and enhancing water quality	163	275	390	901
13. Developing improved economic and institutional arrangements*	41	61	124	108
14. Urban and agricultural water interrelationships	0	20	40	?
15. Synthesizing research efforts through systems analysis	0	10	20	?

*20 SMY in 1972 and 42 in 1977 allocated to the social sciences are not included in these totals but are considered part of the projections for the other missions, 1 through 12, 14 and 15.

Table 2. Comparison of Task Force SMY projections with LRS

	LRS		Task Force			
RPA	1966	1977	Chapter	1966	1972	1977
103	26	66	9	26	50	75
105	149	337	1	38	60	80
			2	28	65	125
			3	54	77	112
			8	6	25	40
			10	23	55	90
			Total	149	282	447
106	73	128	6	43	90	140
			7	30	60	90
			Total	73	150	230
107	220	375	3	6	10	15
			4	94	220	350
			5	10	15	30
			11	90	205	330
			Total	200	450	725
108	41	166	1-12,14,15	---	20	42
			13	41	61	124
			Total	41	81	166
901	112		12	163	275	390
---	0	0	14	0	20	40
			15	0	10	20
			Total	0	30	60
			Grand Total	626	1268	2018

reflects research on wind erosion. It is classified under RPA 107 in the LRS but included in Chapter 3 in the Task Force report.

It is recognized that, at the present rate of training, the universities would not be able to provide the manpower needs reflected in this report. Time and resources did not permit a study of training programs and trends in pertinent disciplines. Some general observations, however, can be made. The enrollment in university undergraduate and graduate programs is influenced by the opportunities afforded the student both during his study and upon graduation. A clear national commitment to provide the resources for solutions of problems in water resource management will be reflected in an increase in enrollment.

Research and training must be integrally related and mutually supporting. The history of agricultural research is inseparably linked to the development of Land Grant Colleges and Agricultural Experiment Stations. The research identified in this Task Force report will provide increased opportunities for training of future scientists in the biological, engineering, and social phases of water as related to agriculture. The recognition of the need and the provision of the resources are prerequisite to attracting the talent needed.

While there is no question that shortages of professional personnel will develop, there are indications that students and institutions will respond to clearly establish needs. For example, the number of institutions offering a Ph. D. degree in Agricultural Engineering has increased from 3 in 1957 to 29 in 1968, the number of graduate students enrolled from 277 to 596, and the number of advanced degrees granted from 65 to 185 in the respective years.

The need for accelerated water research is great if man is to find the way to provide for his needs. Federal and State institutions are ready to tackle the task. We are confident the talent can be found if the need is clearly enunciated and if the resources are made available.

The report consists of statements developing the needs for research in 15 more or less distinct, although somewhat overlapping, areas or missions. A synopsis of each of these areas concludes this introduction.

I Conserving water during storage and conveyance

The use of water for agricultural purposes is the largest consumptive use of water in the United States. Water so used provides the food and fiber essential for the Nation's well being but other demands upon available water resources are mounting to the point where agricultural operations cannot be insensitive to wasteful water use practices. Tremendous opportunities exist for saving water now wasted through inefficient irrigation canals and lost by evaporation from ponds and small reservoirs on farms and ranches.

In 1965, for instance, about 22 percent (25 million acre-feet) of the water withdrawn from surface and ground water supplies for irrigation was lost from its intended use in conveyance from the source to the irrigated fields. Evaporation from ponds and small reservoirs is in the order of 3 million acre-feet a year.

It is estimated that on the order of 10 million acre-feet can be saved by the development and application of techniques to prevent or reduce evaporation from water surfaces and to control seepage.

II Replenishment of ground water

Nearly one-quarter of the water used at present in the United States for domestic, industrial, and agricultural purposes comes from ground water, and the consumption of ground water is increasing significantly each year. Withdrawals are expected to increase from 52 million acre-feet per year in 1960 to over 100 million acre-feet in 1977. While ground-water resources are ample in some sections of the U.S., serious overdrafts are occurring elsewhere. If ground-water resources are to be fully utilized, then a major effort in developing technology for ground-water recharge is required.

Subsurface aquifers provide a huge, low-cost reservoir for water storage that has several important attributes: negligible losses from evaporation, high capacitance permitting large differences in time of storage versus time of use, freedom from contamination by surface sources, uniform temperature, etc.

Means must be found to identify the potential for and enhance natural recharge from stream systems and watershed areas where such recharge will result in an increase of recoverable ground water or enable better regulation of low flows.

Economic ways must be developed for the artificial recharge of ground water and a body of knowledge is needed to permit the design of recharge systems with confidence. Such systems may be used to replenish a dwindling supply, to store surface water conservatively, or to counteract salt water intrusion or land subsidence.

The potential exists to renovate secondary sewage effluent by recharge to the ground water, providing at the same time a new source of water and a solution to a serious pollution problem. Even if only 9 percent of the present secondary effluent lends itself to recharge, this would amount to one million acre-feet per year.

Other questions needing research attention concern identification of the beneficiary to enable cost and benefit allocations, and the socioeconomic basis for assessing ground-water management.

III Conserving soil water and reducing wind erosion

The unequal space and time distribution of precipitation results in a large part of the U.S. having a water shortage during some part of the growing

season. Improved management practices that conserve more of the precipitation after it enters the soil have the potential of tremendous benefits. It has been estimated that a reduction of only 8 percent in evaporation losses would result in increased crop production in the Great Plains alone valued at $600 million annually. Better conservation practices may make it possible to eliminate fallowing from millions of acres where it is now practiced.

Wind erosion control is closely related to soil water conservation. Many practices effective for one goal also aid in the other. The losses from wind erosion, however, are distinct and additive to those due to lack of water conservation.

From a better understanding of heat and water flow through soils and plant canopies, it should be possible to develop practices that enable environmental control for optimization of plant growth and water utilization. Efforts should be directed towards increasing water infiltration, reducing losses from evaporation and deep seepage, increasing water availability to plant roots, developing new plant varieties, and reducing movement of soil particles by wind.

IV Increasing and regulating streamflow

Hydrologic processes are known to be influenced by land use and watershed management practices. Information concerning these relationships from past research and experience is used extensively in implementing operational programs in the Department of Agriculture. But serious knowledge gaps still exist and there is uncertainty, speculation, and controversy regarding the effects upon quantity and quality of water supply, its timeliness, and floods as related to land use and watershed management practices and programs. There is need for a technology with which to evaluate this impact more specifically and to provide the basis for expressing the potential of alternative land use and management programs for attaining the Nation's social and economic goals.

Needed are further studies of basic hydrologic processes on watersheds; development of hydrologic prediction schemes capable of accounting for all precipitation falling on watersheds and river basins; and development of methods for increasing water yield by manipulation of vegetation, management of snowpacks, and harvesting of water from impervicus surfaces.

Considering the potential of watershed management for improvement in the amount and quality of water supplies, abatement of flood damages, enhancement of recreational opportunities, and the prospective public and private investments for watershed protection and development programs, the current efforts in this area are totally inadequate.

V Improving water control and measurement structures

Effective, dependable, and economic engineering structures for handling water and stabilizing stream channels are essential elements in all programs and

activities for development and conservation of water and related land resources. Attainment of such program purposes as erosion and sediment control, flood damage reduction, improved drainage or irrigation, recharge of ground water, development of municipal and industrial water supplies, recreation, and water quality control all require the use of structural measures of one kind or another. To a large degree, the effectiveness and cost of the required structural measures determines the economic feasibility of most water resource development or management programs.

Past research and experience have provided useful guidelines and criteria for design and construction of water control structures, but the opportunities and need for further improvements and refinements through research are evident. Development of concepts and design criteria to improve the performance, reduce overdesign, enhance safety and appearance, and reduce the initial and maintenance cost of water control structures, stream channel improvements, and structures for flow measurements are the objectives of research discussed in this section.

VI Increasing efficiency of irrigation water use

The large and inefficient use of water by irrigation makes research towards increased efficiency of prime importance in the framework of a national water resource program. To obtain significant increases in efficiency requires development and adoption of automated irrigation schemes that enable optimun water application scheduling with a minimum of labor.

Better methods need to be developed for determining optimum time for and amount of irrigation, both in humid areas, with irregular precipitation patterns, and in semiarid areas with limited irrigation water.

Recent emphasis on water quality requires reassessment of present fertilizer-irrigation practices and quantitative determination of the effect of irrigation on water quality.

VII Removing excess water from soils

Drainage of agricultural land has long been recognized as an important factor in increasing the efficiency of crop production. It is estimated that well over 100 million acres of land in the U.S. need to be drained.

Sorely needed to enable better and rational design methods are quantitative data on the effect of degree of drainage on crop growth and economical methods to determine the drainage properties of soils.

Development of improved installation techniques and new materials should lead to significant reductions in cost and hence will enhance farmer income.

Present methods for designing drainage systems are based largely on experience and judgment. Notwithstanding tremendous advances in drainage theory over the last several decades, comparatively little progress has been made in rationalizing design procedures.

VIII Managing Wetlands

Wetlands occupy about 70 million acres of the Nation's land surface. They include bogs, swamps, marshes, wet meadows and tidal flats. Lands with excess water have realized or potential value for many purposes, including tree production, recreation and use for wildlife habitats; they may be useful for storing water, reducing flood hazards or maintaining water supplies for other purposes.

Some consider drainage of wetlands desirable in all instances, but frequently management other than drainage should be preferred. To enable rational decisions and plans for best use of wetlands, however, it is necessary to increase our understanding of their hydrologic characteristics, obtain data on the soil properties that control water movement and retention, and evaluate the effect of alternative management schemes on the economic and social returns from the resource.

IX Increasing efficiency of salinity control and management

Nearly 30 percent of the 40 million acres of irrigated lands in the 17 Western States are sufficiently salt affected to adversely affect crop growth. Excess soil salinity is a potential hazard on half the acreage.

About 50 percent of the water diverted for irrigation returns to the atmosphere as pure water leaving its salt burden behind for removal in drainage water if a profitable irrigation agriculture is to be maintained. The resulting increase in salt concentration of surface waters not only affects agriculture but also may have serious consequences for other uses. The question is often asked whether the use of water for irrigation, with its resulting degradation of quality of surface and ground waters, is economically justified. Certainly, it will become necessary to determine the most efficient manner of water use for irrigation and reclamation to reduce total water use.

An accelerated research program is needed to increase irrigation efficiency, to reduce evapotranspiration without affecting crop yield, to improve leaching techniques, and to adapt plants to higher salt tolerances. Many other important research objectives can be identified.

The need for additional information on effective management of saline water and soil is by no means restricted to the U.S. Increased economic stability in many parts of the world depends on development of irrigation and control of salinity.

X Optimizing water use by plants

Optimization of water use in agriculture to a large degree depends on optimization of water use by plants. The most obvious application of manipulating water supply to plants is irrigation. Irrigation is as old as western civilization; it was practiced 10,000 years ago in Mesopotamia. Although great

progress has been made since in water management for crop plants, there still are important gaps in our knowledge. As the demands for closer control and higher efficiency increase, so does the need for a more sophisticated understanding of the soil-water-plant-atmophere interaction.

Basically, the production of crop plants is the conversion of solar energy to chemical energy. A small part, less than 1 percent, of the incoming solar radiation is fixed by photosynthesis; a far larger part is dissipated by evapotranspiration. Any change that makes possible a reduction in evapotranspiration relative to photosynthesis leads to higher efficiency of water use.

Possibilities include use of better adapted crops, selection or breeding of better adapted varieties and improved cultural practices to reduce water requirements. Alternative routes involve the breeding or selection of varieties for higher photosynthetic efficiency, or development of effective antitranspirants.

Research is also needed to further develop management practices to regulate plant growth. Water stress may initiate flowering and subsequent fruit set, making it possible to regulate time of maturation to facilitate mechanical harvesting or timing of market deliveries.

The potential return on research in this category may be visualized by the observation, that if photosynthetic efficiency were increased by only 1 percent, without any change in water use, we would more than double crop production.

XI Controlling water erosion and sediment

Erosion by water, the dominant conservation problem on 179 million acres of cropland, results in drastic losses to the land. It results in reduced efficiency of farm operations and reduced crop yields; in tremendous losses of plant nutrients and in reduced water use efficiency. Sometimes, it makes once highly productive soil valueless.

Erosion is the source of sediment. Sediment impairs the quality of the water in which it is entrained, and frequently degrades the location where it is deposited. Most sediment consists of soil and rock particles eroded from disturbed lands: crop, range, and forest areas; highway rights-of-way; surface-mined areas; stream banks; and construction sites. Sediment occupies water storage reservoirs, fills lakes and ponds, clogs stream channels, settles on productive lands and interferes with their use, destroys aquatic habitat, creates turbidity that detracts from recreational use of water, degrades water for consumptive or other uses, increases water treatment costs, and damages water distribution systems. In addition, sediment is a carrier of other pollutants such as pesticides.

Sediment derived from land erosion constitutes by far the greatest mass of all the waste materials resulting from agricultural and forestry operations. Rough estimates of the suspended solids loadings reaching the Nation's streams from surface runoff show these to be at least 700 times the loadings caused by sewage discharge.

XII Maintaining and enhancing water quality

Water quality is an important aspect of the broader concern with the quality of the environment. While endorsing the Task Force report on the Quality of the Environment, it is recognized that the evaluation of problems dealing with Water and Watersheds cannot be divorced from considerations of water quality. Sediment, plant nutrients, pesticides, salt and wastes from livestock enterprises all can degrade water quality. Domestic sewage, processing wastes and heat are pollutants from non-agricultural sources that may be moderated by agricultural management.

There is an urgent need for better quantitative evaluation of the relation between pollution and agricultural management practices and for the development of pollution control measures compatible with efficient agricultural production. There is also a need for more effective and economical means of removing pollutants from water.

XIII Developing improved economic and institutional arrangements

Water resource economics and planning was declared by COWRR as a most promising and neglected area of research in terms of immediate and long-term payoff.

Notwithstanding an abundant overall water supply, many problems are caused by water shortages; others, by excesses. Plans for water resource development or management must take account of local as well as regional and national needs. They must consider the needs of both rural communities and urban centers. With increasing urgency, they must consider multiple purposes and their interactions.

The role of water resources in local, regional, and national economics is inadequately understood. Analytical tools of evaluation are unsatisfactory. Techniques of benefit and cost determinations must be improved. Particularly lacking are means to account explicitly for intangible benefits--or costs--and the relation of water resource planning to social values. The impact of institutional arrangements on water use and development must be evaluated and recognized. Especially as it relates to water quality, the social costs as well as the benefits of proposed or estimated standards of achievement must be established.

XIV Urban and agricultural water interrelationships

As our population has grown and personal incomes have increased, the pressures on water resources have mounted. As a result, real or apparent conflicts between agricultural and urban interests are becoming more frequent. Increasingly important interactions between rural and non-rural groups lead to opportunities for cooperation as well as to problems.

This interaction must be recognized explicitly and agricultural specialists should concern themselves with the problems and opportunities it creates. Rural water resource management may well be adapted to provide increased opportunity for recreation to mutual benefit. Farmers may increase their income by providing opportunities for hunting, fishing, and swimming. On the other hand, pollution from urban sources may adversely affect agricultural interests, and agricultural pollution can interfere with urban demands. Many principles of water and soil management can be adapted to provide assistance to urban planners, contractors and homeowners.

Historically, agricultural specialists have "stuck to their knitting." A reorientation of their thinking is necessary but not sufficient. Missing are data to evaluate recreational demand; analytical tools to quantify the relation between recreation and other water uses; sufficient knowledge to predict the effects of excessive traffic on soil and plant behavior; and many other related inputs.

XV Synthesizing research efforts through systems analysis

Water management involves the manipulation of a resource that touches on many complicated interacting forces. On a broad scale, water resource development has to integrate many uses--domestic, industrial, agricultural, recreational, for wildlife, fisheries, and transportation. In another sense, manipulating the water supply affects the growth processes of the plant, the efficiency of water use and energy conversion in crop production, land use variables, and similar dynamic systems.

Systems analysis, developed into a formal arsenal of tools for use in industrial decision making and in military/space projects, provides a mechanism for increasing the effectiveness of water resource planning and of water-related research.

The gainful application of systems analysis to water research and water development planning requires a thorough understanding of the physical and biological processes under study together with knowledge of the theory and application of systems techniques. Unfortunately, few specialists in systems analysis have developed an adequate background of interest and knowledge in agricultural water management; and vice versa, few agriculturists are conversant with systems theory.

Tremendous returns can be expected from a concentrated effort utilizing systems theory in solving research and planning problems of water management.

I Conserving Water During Storage and Conveyance

Situation

The amount of available water is a matter of increasing concern in all parts of the Nation. From the early days of settlement, rights for the use of water have been dominant factors in the development of the arid West. Struggles for the use of water and large investments for development of water resources are traditional in the Western States. But it is now also clear that other parts of the country either have or will have problems imposed by limited water supplies. If the economy of the United States is to continue to grow and prosper, there must be adequate supplies of water available for its population, agriculture, and industry.

Wasteful use of water in any region of the country or by any segment of society is now a matter of concern to all.

About 304 million acre-feet of water were withdrawn from surface and ground water supplies of the United States for rural domestic, municipal, industrial, thermoelectric power, agricultural, and other uses in 1965. Forty-two percent of this withdrawal (75 million acre-feet) was for irrigation and livestock. Thus, withdrawals for these agricultural uses were almost 5 times greater than those for municipal use and exceeded that for industry by 2.5 times and that for thermoelectric power generation by 1.3 times.

Of the water withdrawn in 1965 for irrigation, only 57 percent (65 million acre-feet) was consumptively used in the growing of crops, fruits, and pasture on irrigated fields. About 22 percent (25 million acre-feet) of the water withdrawn for irrigation was lost in conveyance from the source to the irrigated fields. Seepage from canals, evaporation, and use by uneconomic vegetation accounted for this loss. Besides representing a loss of water for its intended use, seepage from the canals also contributes to the waterlogging of 7 million acres of land, much of which might otherwise be profitably used for agricultural purposes. Because of water losses in transit, it is necessary to construct dams, reservoirs, and distribution systems with greater capacity, and consequently, with greater costs than would otherwise be required.

In 1965, about 1.9 million acre-feet of water were withdrawn for livestock, 94 percent of the withdrawal being consumptively used. Fifty-seven percent of the water withdrawn for livestock came from wells, and the remainder from streams, lakes, and stock pond impoundments. Rural domestic purposes required the withdrawal of about 3 million acre-feet of water in 1965, about 70 percent of which was consumed.

Physical regulation and storage is currently the most widely used method of water management. There are 1,562 reservoirs in the United States each having a usable capacity of 5,000 acre-feet or more with an aggregate usable storage of 359 million acre-feet. The total number of impoundments is in the neighborhood of 2 million when smaller reservoirs and stock ponds are included, and the total usable storage capacity of the reservoirs and ponds probably exceeds 400 million acre-feet.

In the order of 25 million acre-feet of water are lost annually by evaporation from the Nation's ponds and reservoirs. Evaporation from small reservoirs and ponds in the Western States alone exceeds 3.4 million acre-feet a year. The volume of water lost from ponds and reservoirs by seepage is unknown, but may be appreciable in the aggregate.

Need for research

Agriculture is the largest consumptive user of water in the United States. Water so used provides the food and fiber essential for the Nation's well-being, but other demands upon available water resources are mounting to the point where agricultural operations cannot be insensitive to wasteful water use practices. Existing agricultural operations are plagued by water losses which increase operating costs, reduce income, and waste a valuable resource.

The average amount of water now lost annually from storage or conveyance for agricultural purposes is slightly greater than the total amount withdrawn for municipal use in the United States. Some of the water lost in conveyance canals is later recovered by pumpage from ground-water storage or is returned to surface streams, but this still represents an economic loss. The potential for conserving water through evaporation suppression and prevention of seepage from conveyance canals is very large. Realizing this potential, however, requires the development of new technology through research.

Objectives

A. Evaporation suppression

1. Chemical retardants. Monomolecular films have reduced evaporation from water surfaces up to 30 percent under controlled experiments but have been little used owing to lack of satisfactory application systems. These surface films are blown by winds to the edge of the reservoir or are broken up by waves, thereby destroying their effectiveness. Under field conditions, evaporation suppression has been about 10 percent under conditions of continuous application of film material. On ponds and small reservoirs what factors determine effectiveness of monomolecular films in reducing evaporation? What are the effects, if any, of such films upon eutrophication of the impoundments? What release rates are required? Can suitable methods be developed for releasing chemical suppressants? What is the cost-effectiveness?

2. Surface covers. Low-density plastic film, that floats on top of a pond, effectively reduce evaporation. These films must be anchored in place to prevent wind from blowing them to one side of the reservoir. Furthermore, some provision has to be made to allow the rain that falls to get into the reservoir and not just pond on top of the cover and evaporate.

3. Reservoir design. In every case, evaporation from a reservoir is proportional to surface area of the pond. Large, shallow reservoirs just lose most of their water. Procedures to decrease the surface-volume ratio to a minimum must be developed. Furthermore, the relationship of pond shape to direction of prevailing winds markedly influences evaporation losses.

B. Evaporation prevention

Alternatives to surface storage. What are the alternatives to ponds and small reservoirs for storage of livestock water supplies on rangelands? Water harvest systems or rain traps for collection and storage of water in tanks or under ground would effectively eliminate water losses by evaporation. What are the site requirements and water supply potentials of rain trap and water harvest installations for livestock use? What are the potentials of aquifer materials for storage of water under ground?

C. Seepage Control

1. Establish methods for estimating rates of seepage. Instrumentation and methods for estimating the hydraulic conductivity of soil and geologic material comprising reservoir sites and canal locations would be developed for better detection, measurement and forecast of seepage problems needing corrective measures. Methods for determining seepage from reservoir basins and the disposition of the water lost in this manner require emphasis.

2. Relations between seepage losses from canals and adjacent water rights. To what extent and under what circumstances do seepage losses from irrigation canals become the source of water used by others? Under what circumstances can seepage losses be depended upon as a source of water supply? What are the negative values of seepage control? Seepage control can become a controversial matter without thorough knowledge about seepage phenomena, the consequences of seepage upon water rights or water use traditions, and the effectiveness and cost of various methods for seepage control.

3. New materials and methods for canal lining. Traditional methods for controlling seepage from canals have included: (1) Hard-surface and exposed-membrane linings; (2) buried membrane linings; (3) earth linings; (4) soil sealants and stabilizers; and (5) grouting, under-sealing, and other means. Improvements are still needed in methods

for installing asphalt, rubber, and plastic membranes. New approaches would include use of chemical compounds for use as waterborne, sprayed, or injected canal sealants. The feasibility of sealing irrigation conveyance canals with seepage transported bentonite or chemical compounds would be determined.

4. New materials and methods for reducing seepage from reservoirs and ponds. Traditional methods for controlling seepage from reservoirs and ponds are basically the same as those used for lining canals. Improved methods for installing asphalt, rubber, and plastic membranes in reservoirs and ponds are needed. What are the possibilities of clay dispersants or chemical compounds for reducing seepage from reservoirs and ponds? What materials and methods are best suited and most effective in preventing seepage from ponds for holding or disposal of animal wastes or other pollutants arising from or associated with farming operations or agricultural enterprises?

Potential benefits

In the order of 8 to 10 million acre-feet per year of water now wasted through inefficient irrigation canals could be salvaged by attainment and application of the research objectives herein portrayed. Another 1 to 2 million acre-feet of water now evaporated annually from the surface of ponds and small reservoirs could be saved. Thus, the research has the potential of saving water equivalent to a new water supply in the order of about 10 million acre-feet per year.

Waterlogging of 7 million acres of land because of seepage from canals would be greatly reduced, permitting productive use of much of this land which is now idle and unsightly. In their present condition these lands are also breeding grounds for mosquitoes and often times a public nuisance. The costs and inconveniences of hauling water for livestock would be greatly reduced.

Present and projected research effort

In FY 1966, 40 SMY's were devoted to research on conserving water during storage and conveyance. To achieve the level of research needed, this should be increased to 60 SMY's in 1972 and to 80 SMY's in 1977.

II Replenishment of Ground Water

Situation

Nearly one-quarter of the water used at present in the United States for domestic, industrial, and agricultural purposes comes from ground water. Irrigation is the single greatest user. The consumption of ground water is increasing significantly each year. Even in the Eastern part of the country, increasing development is being made of ground water because of its desirable properties, including the absence of sediment and bacteria and consistency of temperature. This trend has been further accelerated in recent drought years when ground water proved to be more dependable than surface supplies. If nuclear explosions should contaminate surface water supplies, the principal or even only uncontaminated source of water would be ground-water reservoirs.

While ground-water resources are ample in some sections of the U.S., serious overdrafts are occurring in the Great Plains, the arid West and parts of the humid areas in Arkansas, Mississippi, Florida, and eastern Texas Coastal Plains. The High Plains of Texas provide an example. Currently about 7 million acre-feet are withdrawn annually from the Ogallala formation. Ground water levels are dropping rapidly. The present rate of pumping is about 50 times the natural recharge rate.

Water shortages are, in general, regional in nature and fluctuate drastically with time. In principle, there is sufficient water available if the problem of distribution and storage can be resolved. Aquifers provide extensive, conservative and cheap storage facilities. They circumvent the need for expensive surface reservoirs with related losses due to evaporation. At present, they are not used to the fullest advantage.

Nationally about 11 million acre-feet of domestic waste are now handled by public systems annually. Most of the effluent from secondary treatment plants is discharged into surface channels or streams. Present techniques result in serious problems of maintaining adequate water quality and in less than maximum efficiency of total water resource utilization. The reuse of such waters by renovation through recharge to the ground water could be an important means of augmenting water supplies in areas of shortage.

Need for research

If ground-water supplies are to be fully utilized in furnishing water for irrigation, municipal and industrial needs, and to augment streamflow during droughts, then a major effort in developing technology for ground-water recharge--both natural and artificial--is required.

Very limited information is available on the factors influencing the loss of streamflow by absorption in alluvial channels, yet this is probably the principal

mechanism of natural ground-water recharge especially in arid and semiarid regions. The potentials of streamflow regulation to enhance ground-water recharge appear to be great in some areas. The relationships between ground-water recharge associated with transmission losses and water yield as streamflow at downstream points also need clarification. This has an important bearing on the possibilities for applying range improvement and conservation practices without adverse effects on downstream water supplies. Range treatment measures which might retain on the land, for improved forage production, some part of the rainfall which would otherwise run off, but which would not in any case reach a major stream, would have no effect on downstream water supplies.

The design of artificial recharge basins suffers from an inability to adequately predict the rate of recharge, and from lack of understanding of the effects of management of the recharge site. To maintain maximum rates and high efficiency of recharge generally requires alternate periods of charging and drying of the site. Criteria for determining optimum patterns of cycling, and hence for design of recharge systems, are sorely need.

Ground-water reservoirs are certain to become increasingly important as essential features of both large and small scale water developments. For example, the ground-water basin of the San Joaquin Valley is an important element of the California Water Plan. Utilization of ground-water basins implies using these underground reservoirs for transmitting and storing varying portions of an area's water supply. These functions are performed in close conjunction with surface facilities, such as reservoirs and pipelines, to meet the water requirements of an area.

Only in recent years has much emphasis been given to definition and study of the 3-dimensional water basin, including subsurface flow, for a better understanding of the total flow system. Within these systems, areas of recharge and their characteristic rates of recharge are important factors to ascertain prior to developing any comprehensive recharge study.

Although the volume of ground-water storage is often large, it is usually not feasible to utilize it all. Besides the increase in water cost due to the greater head lift and the deeper wells that may be required, there is usually a worsening of quality as ground-water levels are lowered. Other undesirable situations may also develop such as intrusion of salt water into coastal basins and land subsidence. Subsidence alone has caused 4 to 5 million dollars worth of damage to water wells in the Santa Clara Valley of California. Artificial recharge is one way of maintaining ground-water levels within economic limits.

Water clarification will be required for much of the water to be recharged by artificial means. Recent research on water clarification by means of polyelectrolytes has demonstrated that drastically reduced costs are possible. Other electrokinetic techniques may also be applicable. The newly discovered

chemicals, principles, and methods have not yet been proven as workable field units although their potential for reducing costs of ground-water recharge have been demonstrated. Other recent research indicates potential for increasing recharge rates through individual well or shaft modifications that are at least 4-5 times the conventional rates. This discovery has not been developed sufficiently to allow practical use at this time. The technology available at this time does not permit design of low-cost recharge systems.

A major consideration in the use of recharge as a means of disposing of treatment plant effluent is the effectiveness of the recharge system in renovating the water. Soils and plants are known to possess remarkable potential for water purification, but present understanding is inadequate to take full advantage of this fact.

An indication of the urgency of some of the questions discussed above is given by the strong interest of the Federal Water Pollution Control Administration, U.S. Department of the Interior, in initiating and supporting research on the recharge of domestic waste effluent, and by the crash program initiated by the Geological Survey, U.S. Department of the Interior, for developing ground-water recharge technology for the High Plains of Texas. Similarly, a number of agencies in USDA face pressing problems. For example, ASCS is anxious to develop a program to further recharge by wells through cost-sharing, but finds itself without adequate guidelines to establish standards that will provide a reasonable guarantee of success. The SCS, in developing plans for watershed development projects under PL-566, frequently is not able to identify the beneficiary, and hence, has difficulty in completing its cost allocation and cost-sharing computation.

COWRR has recommended, "because of the prospect of critical ground-water problems in selected areas and the increasing importance of ground water as a source of water supply," that research effort in this area be increased to five or six times its 1966 level.

Objectives

A. Develop and assess land and water management practices to sustain and/or improve the quantity and quality of water recharged.

   1. Find means of quantitatively describing the hydrogeologic system--Evaluation of the dynamics of water infiltration and underground movement must be preceded by a description in quantitative terms of the aquifer and its properties, and of the overlying strata. This rather obvious statement is made pertinent by the uncomfortable fact that, notwithstanding years of hydro-geologic research, we are not now able to provide, at reasonable cost, the necessary answers to the questions implied. Determination of aquifer properties, of hydraulic conductivity of the overburden as a function of antecedent moisture content and time of inundation, and similar data are wrought with uncertainties.

2. Devise and evaluate surface management practices. What is the effect of land management practices increasing surface water detention on water infiltration and recharge? What are the influences of antecedent moisture, channel size and shape, bank and bed materials and treatments, and depth and duration of flow on channel transmission losses? How do land management practices such as use of fertilizers and pesticides affect the quality of water recharged, both temporally and spatially? To what extent can base flow be modulated by manipulating recharge rates? What is the effect on total water supply of land and stream manipulation?

3. Delineate zone of influence. One critical problem that confronts any effort at ground water management concerns the identification of the beneficiary. Allocation of costs--or establishment of project feasibility--requires determination of the disposition of the water recharged and the manner and degree of recovery. Such problems require economic and legal evaluation based on physical data.

B. Devise economic ways of artificial ground-water recharge

1. Develop means for water clarification. Especially in the case of recharge wells, but not exclusively so, the life and effectiveness of the recharge facility depends greatly on the turbidity of the water. The use of coagulants and flocculants, in coordination with stilling basins, offers the opportunity for significant gains in the economics of recharge. For flooding basins, periodic rehabilitation of the surface soil layers may be preferable.

2. Develop and evaluate alternate recharge systems. Recharge wells, shafts and flooding basins offer alternative means of approach. Adequate criteria for design and operation are lacking. As they are developed from intensified research, it should become possible to determine their relative suitability for specific applications, and to make cost comparisons for economic evaluation.

3. Evaluate recovery of recharged water. The economics of artificial recharge depends in part on the effectiveness of recovery and, for the individual operator, on his ability to recover this water himself. The extent of ground water mound build-up and dissipation, the effect of pumping from adjacent wells, and the loss of water to nonbeneficial uses all need to be evaluated. Technology must be developed to enable prediction of project effectiveness prior to installation.

4. Evaluate change in quality of water from recharge. Aside from the quantity of water it is feasible to recharge, the question of quality is of paramount importance. It involves two aspects: the introduction of pollutants into the aquifer from surface sources--such as pesticides--and the change in water quality through its contact with chemicals

inherent in the soil. The passage of water through a soil region high in boron, for example, can make the water totally unsuited for irrigation; contact in passing with a region high in sodium may affect not only its suitability but could change the properties of the aquifer adversely.

C. Renovate secondary sewage effluent by recharge

1. Establish feasibility of intermittent inundation. How does intermittent inundation with sewage effluent affect the soil properties? What are the flow patterns developed, and how do they change with time? What will be the oxygen status?

2. Evaluate change in water quality. What improvement in water quality takes place by filtration through vegetation? What biological and chemical processes take place in the vegetation regime and in the soil? To what extent can the oxidation potential of the soil atmosphere be manipulated to oxidize the organic matter and/or reduce the nitrates introduced?

3. Consider alternative means of reuse. In part depending on the success of quality enhancement, recharged water from sewage can be recovered for reuse as a municipal supply, for use in irrigation or for other uses. Recharge basins may serve a dual purpose as a recreation resource. The economic feasibility of the recharge schemes will depend on the use to be made of the end product, which in turn will be influenced by the hydrogeology of the basin and the effectiveness of water renovation.

D. Provide socioeconomic basis for assessing ground water management.

1. Evaluate economics of present versus deferred ground water development. As ground water withdrawal rate approaches or exceeds recharge, more attention should be given to the social benefit from such use of water; determination of the economic limits of withdrawal; and analysis of efficiency-improving measures.

2. Provide socioeconomic data and evaluations relevant to the selection of areas for ground water recharge. This includes consideration of the economic importance of ground-water resources in areas identified as possessing hydrologic and geologic potential for recharge.

3. Evaluate legal and institutional requirements necessary for improved ground-water management and allocation, and which bear upon recharge.

Potential benefits

The ultimate potential benefits of ground-water recharge are hard to assess because of many unknown factors. There are hundreds of ground-water basins in the country, each with its own particular hydrology, geology, and economic environment. It is clear, however, that water supplies can be economically augmented by natural and artificial recharge of ground-water basins from precipitation and surface waters at times of excess. Ground water augmentation from secondary sewage effluent will yield the additional benefit of resolving a disposal problem.

Underground storage has the advantage of being available on demand, avoiding evaporation losses, and interference with alternate development and use of land resources on the surface. It is free from atmsopheric fallout and provides ready areal accessibility.

Ground water withdrawals are expected to increase from 52 million acre-feet per year in 1960 to over 100 million acre-feet in 1977. The estimated recharge potential for the Ogallala formation in Texas from local runoff is 3.7 million acre-feet. Present plans call for importing 14 million acre-feet of water annually to the region; of this amount, possibly 5 million acre-feet will need to be stored underground.

Even if only 9 percent of the present secondary sewage effluent lends itself to recharge, this would amount to one million acre-feet per year.

Present and projected research effort

Present effort in ground-water recharge is approximately 30 SMY. To achieve the level of research needed, this must be increased to 65 SMY in 1972 and 125 SMY in 1977. Of these 125, approximately 4 would be devoted to socio-economic studies.

III Conserving Soil Water and Reducing Wind Erosion

Situation

Virtually all of the Nation's water supply arrives as precipitation upon the land. The unequal space and time distribution of this precipitation results in a large part of the U.S. having a water shortage during some part of the growing season. Physiological and biochemical processes in plants which result in the quality and quantity of product are influenced to a large degree by soil water. About 70 percent of the precipitation which falls upon the land is lost from the soil by evaporation and transpiration. In the future, greater emphasis will have to be placed on management of precipitation and the path soil water takes in the hydrologic cycle if the future needs for food, clothing, shelter, and recreation are to be met. Many soil water conservation practices are now in use such as stubble mulching, contouring and terracing, mulching, bench terracing, pitting, and skip-row farming. Despite these advances, soil water is the major limiting factor for agricultural production in much of the Nation. A continued need for conserving soil water and using this water more efficiently will exist for the foreseeable future.

Wind erosion control is closely related to soil water conservation. Wind erosion of soil particles not only is a loss of valuable nutrients for crop production, but it results in a reduction in water infiltration and storage by soils. Many practices which are used to conserve soil water have a multiple purpose of reducing wind erosion.

Stubble mulching, stripcropping, shelterbelts, emergency tillage, cover crops, controlled grazing, petroleum and chemical soil stabilizers, regrassing, and reforestation all are used at present to control wind erosion. Application of these methods has produced significant advances in wind erosion control. At Dodge City, Kansas, there were 120 duststorms in 1936-37 and only 40 in 1955-56 when drought conditions were more serious than during the 1930's. Despite these advances, wind erosion remains a serious problem and will continue to be a serious problem in the foreseeable future. Estimates indicate 48 million acre-feet or 1.2 inches of soil has been removed from about 750,000 square miles in the Great Plains during the 40-year period from 1922 to 1961. Serious wind erosion also occurs each year on the sandy and muck soils in Michigan, Ohio, and Minnesota; along the Columbia River Basin; and in the Southeastern Coastal States.

Need for research

Present technology reflects considerable progress in ways to improve storage, conservation, and use of soil water. Though this technology represents milestones in the efficiency of use of soil water, it is inadequate to meet the

future demands that will undoubtedly be placed upon range, forest and crop lands. Future agricultural production will demand greater control over the environmental parameters and better management and automation of the factors of production. Technological advancements in the conservation and use of soil water will be required to reach this degree of control.

Present technology of wind erosion control is inadequate since severe erosion still removes valuable top soils from large areas of the Nation and the abrasive action on seedlings reduces yields of many field and vegetable crops. Technological advances resulting in greater control over soil erosion processes will be needed to meet future agricultural demands.

Research to conserve soil water will be needed by Federal and State agencies with a greater emphasis on regional research. This research will need close coordination between agencies to avoid duplication and maximize the use of the research dollar. Perhaps the greatest need will be the training of scientists to conduct this imaginative and creative research. At the present time, there is a shortage of trained scientists represented by the scientific disciplines associated with soil water conservation and this shortage is expected to increase within the next decade.

Objectives

1. Develop fundamental equations involved in water and heat flow in soils for more effective procedures to monitor and utilize soil water. Flow is currently amenable to physical and mathematical analysis for only a few simple cases. Investigations need to uncover methods to accurately predict soil water content and energy with which water is held in soils for any soil-plant system. Studies should reflect methods to quantitize deep percolation of soil water.

2. Develop management practices, plant varieties and environmental requirements to make efficient use of soil water though the various stages of plant growth. Studies should include plant breeding for efficient water use and water retention within the plant. Various cropping systems need study to develop a system for optimum water use.

3. Develop alternative techniques for reducing water loss from soil surfaces which will result in little or no detrimental effect on crop yield. Studies are needed on various mulches, tillage practices, surface modifications and chemical additives as they influence evaporation suppression.

4. Develop soil surface and profile modification or management practices to enhance water infiltration, transmission, storage and use by plants. Studies should be conducted on precipitation (rain and snow) management to enhance water use. Studies should be conducted on water retention and transmission properties of soils and methods to improve these properties for better water use by plants.

5. Develop new concepts and fundamental equations involved in erosion by wind. Investigations should lead to the development of methods to accurately predict soil wind erosion and new ideas for controlling this process and conserving soil water.

6. Develop soil surface management or modification techniques to reduce seedling damage from cutting and abrasion resulting from wind blown soil particles. Studies should be initiated on mulches, tillage practices, surface modifications, and chemical additives for reducing wind blown soil damage. Investigations should also be initiated on plant breeding to resist seedling damage by wind blown soil particles.

7. Carry out economic evaluations of water conservation practices on non-irrigated land. As new moisture conserving practices and technology are developed, economic studies should be made to determine cost effectiveness of practices; capital requirements and annual costs of application; and effects on production in terms of operator net income.

8. Analyze substitution possibilities, in an economic sense, of water conserving and soil conserving practices. This includes determination of production response, under given conditions, of practices having different kinds of conservation purposes--such as to reduce wind erosion, or to reduce moisture evaporation or transpiration.

9. Analyze costs and returns of snow catchment practices on farms, such as shelterbelts, snow fences, terracing, stubble control, etc.

Potential benefits

The benefits from soil water conservation research would include: reduced cost of agricultural production, increased efficiency of water use, reduced hazards of erosion and flooding on watersheds and reduced pollution of water. A reduction in evaporation of 15 percent in the ten Great Plains States alone would amount to an annual savings of 300 million acre-feet of water. An additional benefit from evaporation reduction would be that much of the land now fallowed could be cropped continuously. In areas of moisture deficiency, millions of acres are fallowed each year to build-up soil water for the succeeding crop. Evaporation reduction research would eliminate most of this fallowing practice.

Benefits from controlled soil erosion are increased income from agricultural production, reduced cost of maintenance of roads and fences and reduced air pollution. For example, an average of about 3 million acres in the Great Plains have been damaged by wind erosion in the past 10 years. Reduced dust and air pollution would affect the health of, and aid in the prevention of accidents for, some 14 million people and 36 million head of livestock.

Present and projected research effort

It is estimated that the present effort of 60 SMY should be increased to 87 SMY in 1972 and 127 SMY in 1977.

IV Increasing and Regulating Streamflow

Situation

Because of the great variation in distribution of water supplies over the country, some localities are deficient and, with addition of 100 million people in the next 32 years, supply problems will become acute. A major water resource problem will be that of providing sufficient additional water supplies for agricultural, municipal, rural, industrial, and recreational uses and for transportation, waste disposal, and water quality control. At the same time, excess water resulting in floods has a major impact upon social and economic values. The Senate Select Committee on Water Resources, in 1961, estimated potential upstream and downstream flood damages would amount to $1,313 million annually by 1980, if no additional flood control projects were undertaken. The portion of this potential flood damage occurring in upstream areas (watersheds less than 390 square miles in size), amounting to $574 million annually, was reported as representing only a part of the upstream damage.

The average annual water budget (precipitation) for the conterminous United States is 4.75 billion acre-feet, probably 90 percent or more of which falls on land used for agriculture (including rangeland) and forestry. About 60 percent of the present national water supply originates as streamflow from forest, brush, and related range and alpine areas that occupy approximately one-third of the country and comprise the headwaters of every major river system.

Numerous experiments on plots and small watersheds have shown conclusively that using the Nation's farm, forest, and rangeland for production of essential food and fiber crops has a decided influence upon operation of the hydrologic cycle. In general, a greater proportion of precipitation occurs as surface runoff from clean-tilled crops in short rotations and from shallow soils than from crops in grass-based rotations, small grain, hay and pasture, and deep soils; other factors being equal surface runoff from rangelands is inversely proportional to the density of vegetative cover and intensity of use; total water yield from woodlands and forests protected from fire and grazing and with other appropriate silvicultural practices is less than from improperly protected and managed woodland and forest areas. Trees and deep-rooted crops have a greater consumptive use of water than shallow rooted grasses and crops. Phreatophytes are usually wasteful users of water and removal of riparian vegetation has been shown to increase streamflow.

A major potential source of additional water for meeting increasing demands lies in capture of part of the 3,355 million acre-feet of water that are now being returned to the atmosphere by evapotranspiration. A corollary source is alteration of streamflow timing in order to make more of the existing supply of water available when needed.

Programs and activities of the Department of Agriculture have a great influence upon the Nation's land and water resources. Authorized operational programs in the Department relating to water and water resources include: (1) management of 186 million acres of national forests and national grasslands; (2) technical and other assistance to soil and water conservation districts and individual farmers in planning and installing soil and water conservation measures; (3) cost-sharing assistance to farmers for specified soil and water conservation practices; (4) loans to individuals and water-use associations for water facilities, irrigation improvements, rural waste-disposal systems, soil and water conservation, and erosion prevention and related measures; (5) assistance to local sponsors of resource conservation and development projects; (6) assistance on rural renewal projects; (7) planning and financial assistance and loans to local watershed organizations in planning and carrying out works of improvement for flood prevention and damage abatement, irrigation and drainage, fish, wildlife, recreation development, municipal and industrial water supply, rural water supply, and water quality improvements; (8) participation in cooperative State and private forestry programs; (9) credit and other assistance to organizations furnishing electric energy to persons in rural areas, among other things to finance construction of steam and hydroelectric generating plants; and (10) participation in comprehensive river basin planning.

Similarly, the Department of the Interior and the Department of Army have numerous programs and activities that are designed to affect the utilization of our water resources. For example, the Bureau of Reclamation operates over 200 large storage reservoirs for irrigation, flood control, and other uses.

Need for research

Hydrologic processes are known to be influenced by land use and watershed management practices. Information concerning these relationships from past research and experience is used extensively in implementing land and water resource programs in the fields of agriculture and forestry. But serious knowledge gaps still exist and there is uncertainty, speculation, and controversy regarding the effects upon quantity and quality of water supply, its timeliness, and floods as related to land use and watershed management practices and programs. There is need for a technology with which to evaluate this impact more specifically and to provide the basis for expressing the potential of alternative land use and management programs for attaining social and economic goals inherent in the Nation's land and water resources.

Hydrologic prediction schemes for watersheds and river basins with capabilities of accounting for all precipitation falling on them--whether to surface runoff, infiltration and return flow, deep percolation, soil moisture for evapotranspiration, or surface storage--are required. They must also have the capability of providing dependable, authoritative estimates of volumes, magnitudes and probabilities of single flood events essential to the economical design of spillways, channels, and other engineering works for various water control purposes.

The present studies by Federal agencies and State agricultural experiment stations of hydrologic processes on watersheds have the proper orientation but need to be supplemented and continued.

Research on the methods to increase water yield is relatively new. Studies now in progress are producing some interesting and worthwhile results but many are longtime in character and only a few of the many problems and relationships are being explored. Empirical studies on experimental watersheds have shown that water yields can be increased by removal of vegetation. But the basic relationships between plants and water use need to be better understood before operational programs for increasing water yields can be applied on a planned basis to meet various management objectives. In many instances, increased water is needed only to meet seasonal shortages, in others only for emergency shortages on an intermittent basis. Management for meeting these goals requires a great deal more refinement than is now possible. There is also a need to establish criteria for determining what sites have potential for providing more water under management, what quantities and timing of delivery can be expected, and how far from supply sources will increases be effective.

The present program is well formulated but small. There is not adequate research on the basic elements of the hydrologic cycle that influence water yields. Research on these fundamental processes must be continued and strengthened.

There is potentially great economic significance attached to measures that increase water supplies, depending on the costs of additional water supplies in relation to the value of water to primary users and associated benefits for regional income and development. These factors should be thoroughly examined and assessed as new technology is developed for increasing water supplies. As a basis for allocating research and program resources into most productive uses, there will be urgent need for economic evaluation of alternative methods for augmenting and conserving water supplies, such as weather modification and desalinization.

Objectives

A. Develop basic processes in the hydrologic cycle and mathematical equations for predicting the response of watershed systems to management practices and hydrologic sequences.

   1. Precipitation and climatic patterns and their magnitudes, probabilities, and sequences by regions would be developed as essential information for both research in watershed hydrology and for use in operational programs of watershed management.

   2. Dimensional characterization of soils and vegetation for computing rates and amounts of infiltration, evapotranspiration, subsurface flow in soils, and excess precipitation of various soil-cover-treatment complexes, as essential components in a watershed hydrology model

based upon the water balance concept, would be developed. New knowledge about these phenomena and their interaction in the context of complex watershed systems is an urgent need.

3. Aquifer-streamflow relationships in watersheds. Lack of knowledge on the disposition of water absorbed into soil-cover-complexes is one of the major current limitations of deterministic hydrology. The potential for influencing deep seepage by surface treatments of watersheds, the capacity of aquifers and geologic strata to store and transmit water, and losses and gains of streamflow in stream channel systems will be developed.

4. Hydrodynamics of channel systems in watersheds. Concepts and parameters for computing overland flow of precipitation excess from soil-cover-treatment complexes, and the interchange of surface and subsurface waters (including water stored or detained in ponds and reservoirs) would be developed for flood routing and water accounting by watersheds and river basins.

5. Synthesis of runoff and streamflow regimes. Mathematical models to accurately simulate streamflow from meteorological observations and measurable physical characteristics of watersheds would be developed, having capabilities for: (a) computing infiltration, rainfall excess, overland and subsurface flow, and streamflow in the normal chronological sequence of the distributed system in a watershed; (b) relating computed soil moisture balances to expectancies of precipitation sequences; (c) predicting the downstream attenuation of hydrologic changes induced by land use and water management schemes in upstream areas; (d) quick estimates of floodflows and water yields from complex watershed for use in design of low-cost, low-hazard projects; and (e) identification of those features controlling the hydrologic system of a watershed, for use in optimizing utilization of water and related land resources.

B. Increasing water yield from water supply areas

1. Manipulating vegetation to increase water yields. Effective measures for augmenting water flows will require research to: (a) improve methods for measuring evapotranspirational processes through energy budget techniques, (b) develop new physiological techniques for suppressing transpirational losses of water by vegetation, (c) determine transpirational characteristics of selected plant species with low water consumption for vegetation management, and (d) develop cheap but effective methods for converting non-commercial but high water-consuming vegetation types to more productive types with lower water demand.

2. Managing snowpacks to extend periods of snowmelt runoff. New techniques are needed to: (a) delay streamflow from western alpine areas further into the summer low flow period through improved mechanical and vegetative management techniques for concentrating snow into drifts and reducing snowmelt rates, (b) increase amounts of streamflow from western

alpine and other snowpack surfaces by development and use of cheap but effective evaporation suppressants, such as fatty alcohols, for reducing evaporational losses of water, and (c) encourage deposition of snow into deep, well-insulated drifts that melt slowly and prolong streamflow by improved methods of thinning and harvesting snowpack forests.

3. Harvesting water from impervious surfaces. Research is needed to: (a) develop techniques to reduce cost of water harvesting by reducing permeability of soil, by application of sprayed pavements by use of plastic and metal films and artificial rubber sheeting, and (b) develop new concepts, materials, and methods to reduce costs of storing water and to reduce loss of water from storage facilities.

C. Economic impacts of streamflow modulation by watershed structures and management

Economic models to parallel the proposed hydrologic modeling of watersheds is a primary aim of this research. The models would simulate production conditions under alternative watershed management approaches as a basis for predicting economic effectiveness and acceptability of proposed projects. Also included would be economic studies of alternatives to watershed structures, including institutional as well as land treatment and management alternatives. Criteria for identifying and evaluating the economic effects ("onsite" and "offsite") of watershed structures would also be developed.

Potential benefits

Successful completion of the research outlined above would result in: (1) significant increases in high-quality, usable water, particularly during low-flow periods; (2) cost savings from more accurate estimates of sizes of spillways, bridges and culverts, and floodways required to safely handle peak flood discharges of specified frequency from upstream watersheds; (3) greater accuracy of predicted flood occurrences and damages in upstream areas; (4) more dependable forecasts of water yield and supply available from upstream watersheds; (5) increased potential for maximizing flood reduction benefits, and (6) the technology required for evaluating the effects upon downstream water supply of alternative land use and water management schemes upstream.

The research herein described is one part of the national goal in water resources research projected in the document, "A Ten-Year Program of Federal Water Resources Research," developed by the Office of Science and Technology, February 1966.

Present and projected research effort

The 1966 level of research in this area approximated 94 SMY. In line with the recommendations of OST, it is recommended that this effort be increased to 220 SMY in FY 1972 and 350 SMY in FY 1977.

V Improving Water Control and Measurement Structures

Situation

Work plans approved for operations under the Watershed Protection and Flood Prevention Act (PL-566), by June 30, 1967, and covering 2.5 percent of the area of the United States, included structural measures having an installation cost of $1,086.4 million. This backlog of engineering work in the Department of Agriculture, which has been justified by benefit-cost appraisals, is comprised of items such as: 4,736 floodwater-retarding structures; 1,806 grade stabilization structures; 151 combination floodwater-retarding and grade stabilization structures; 358 multipurpose reservoirs; 95 single purpose reservoirs and 14,996 miles of stream channel improvement.

In FY 1967 the Soil Conservation Service under PL-46 provided technical assistance for construction of 58,846 farm ponds; 2,318 debris basins, 284 miles of dykes and levees; 5,745 miles of field drainage ditches; and 40 miles of floodways. The amount of such construction work usually increases each year.

There are more than 3 million miles of stream channels in watersheds under 500 square miles in size in the United States. Of these many miles, the vast majority are considered to be tolerably stable. Some are aggrading and becoming choked with bed material and objectionable vegetation with consequent high frequency of bottom land flooding. Some are deleteriously degrading, threatening the stability of structural or other developments along watercourses and inducing undesirable tributary headcutting. On an average, about 1,400 miles of stream channel improvement are authorized each in watershed work plans approved under provisions of PL-566.

The Department of Agriculture and the State agricultural experiment stations operate experimental watersheds where measurements of streamflow or runoff are made by means of flumes, weirs or other structural devices. Most present structures for measuring runoff constrict the flow, often causing undesirable upstream ponding and associated deposition which distort the flow hydrograph. Expensive and time-consuming field measurements of flow velocity are now required for calibration of the larger flow measurement structures, including even those built according to specifications developed from laboratory ratings and tests of individual scale models prior to construction.

Agencies in the Department of the Interior also are engaged in research and remedial programs related to stream management.

Need for research

Effective, dependable, and economic engineering structures for handling water and stabilizing stream channels are essential elements in all programs and activities for development and conservation of water and related land resources.

Attainment of such program purposes as erosion and sediment control, flood damage reduction, improved drainage or irrigation, recharge of ground water, development of municipal and industrial water supplies, recreation, and water quality control all require the use of structural measures of one kind or another. To a large degree, the effectiveness and cost of the required structural measures determines the economic feasibility of most water resource development or management programs.

Past research and experience have provided useful guidelines and criteria for design and construction of water control structures, but the need for further improvements and refinement through research is evident. This research will reduce the possibilities of overdesign, which increases the costs unjustifiably, or underdesign, which may result in costly structure failure.

Objectives

Development of concepts and design criteria to improve the performance, reduce overdesign, enhance safety and appearance, and reduce the initial and maintenance costs of water control structures, stream channel improvements, and structures for flow measurements are the objectives of this research. Subjects for research include:

A. Spillways and outlets for farm and ranch ponds, floodwater detention and water supply reservoirs, and structures for channel grade stabilization.

1. Develop effective debris guards and trash racks for floodwater detention reservoirs with and without permanent pools.

2. Determine circumstances under which destructive cavitation may exist in closed conduit spillways and develop shapes of transition sections to avoid or minimize low pressures that induce cavitation.

3. Develop methods to dissipate the energy of water and control scour at outlets of closed conduit spillways.

4. Develop information about gradients of water temperature in flood detention reservoirs, changes in temperature of water passing through drop inlet spillways, and devise outlet systems for discharging waters of selected temperature to maintain or enhance environments for fish.

5. Develop appurtenances to facilitate passage of fish at dams on headwaters streams.

B. Construction and protection of earth-fill dams

1. Develop criteria for designing earth-fill dams and levees based upon physical and chemical properties of fill materials.

2. Develop methods for protecting earth-fill dams from destructive wave action, including consideration of both vegetative and structural measures.

3. Devise methods for economically stabilizing earth spillways at dams for flood detention and other purposes.

C. Hydraulic design of stream channel improvements and protective works.

1. Develop generalized design criteria for the hydraulic layout, and design of channel transitions and confluences for supercritical flow.

2. Define more precisely the fluctuations in water surface levels in curves, tangents, and straight reaches of rectangular and trapezoidal channels when flow is near critical depth.

3. Determine the range and conditions of applicability of various means for stabilizing channel banks and controlling alignments, including such as riprap, dykes, jetties, groins and other mechanical devices used separately or in combinations with grass, shrubs, or other vegetation.

4. Define the limits of bank stabilization work required to confine the channel to designed alignment and cross-section.

5. Establish criteria for determining protective works needed to prevent scour at grade control structures on channels with erodible beds and criteria for their design and placement.

D. Flow measurement devices.

1. Develop and calibrate flumes, weirs, gates or other devices or concepts for automatically measuring rates of flow in natural stream channels.

Potential benefits

Experience to June 30, 1967, on 817 work plans authorized for operations under PL-566, suggest that in the order of 150,000 community-type water control structures would be required for various purposes as the PL-566 program is applied in the balance of the country needing it. Some 320,000 miles of stream channel improvements would also be included. At today's prices these measures would cost about $14,500 million. In fiscal year 1967, the Soil Conservation Service provided technical assistance for the design and construction of about 59,000 farm and ranch ponds which cost around $74 million to build. Projecting the 1966 experience suggests that in a 5-year period, in the order of 295,000 ponds costing $370 million would be built in soil and water conservation districts. During the last 10 years, the cost-share payment for about 28,000 water control structures under the Great Plains Conservation Program has amounted to $9 million.

The performance and efficiency of water control structures such as indicated above will be improved by this research and their costs reduced. Improved predictions of flood peaks and volumes, resulting from better flow measurement

devices, will result in more refined estimates of flood damages and water supplies. Refinements in streamflow measurements will also result in smaller design safety factors and, thereby, further reduce the costs of dams, spillways and channels included in water resource projects and programs.

In addition to applicability to water resource activities authorized for the Department of Agriculture, results of this research will be extensively used by private engineers, States, and various Federal agencies outside USDA, including, Corps of Engineers, Bureau of Land Management, Bureau of Public Roads, and the Bureau of Reclamation.

The research herein described is one part of the national goal in water resources research projected in the document, "A Ten-Year Program of Federal Water Resources Research," developed by the Office of Science and Technology, February 1966.

Present and projected research effort

In FY 1966 USDA and State agricultural experiment stations devoted approximately 10 SMY per year to this area of research. It is recommended that support of this research be increased to 15 SMY in FY 1972 and to 30 SMY in FY 1977. The facilities for research on conservation and irrigation structures recommended in Senate Document 59, 86th Congress, should be provided and fully staffed. These recommended increases are in line with projections by COWRR.

VI Increasing Efficiency of Irrigation Water Use

Situation

More than 44 million acresof land were irrigated in the U.S. in 1965. Of the 30 percent of the precipitation that reaches the streams or ground water of the continental U.S., about 1/4 is actually withdrawn for use in irrigation, industry, and municipalities. Less than 1/3 of the water withdrawn, or about 100 million acre-feet, is actually consumed; about 90 percent of this is used by agriculture. It is estimated that, on the average, over 50 percent of the water applied on the farm runs off or is lost to deep seepage, most of the loss being by subsurface flow.

The amount of water used by agriculture is projected to increase. Since 1940 water use in agriculture has grown by 60 percent, however, the amount going to nonagricultural uses increased by 190 percent during the same period. As a percentage of all water used, agricultural use is projected to decrease from 41 percent at the present time to 31 percent in 1980. As the competitive pressures from industrial, recreational, and urban uses for more water grows, agriculture will increasingly have to justify its use of water. At the same time, agriculture must increase the efficiency of water use, as well as look to newer and better ways of developing additional sources of water.

Irrigation has been practiced for more than a century in the arid West; general irrigation management practices have been developed through research and experience. Since the mid 1940's irrigation has increased rapidly in the semiarid and humid areas. Experience quickly showed that irrigation practices developed for the arid West could not be applied directly to these areas because of different crop varieties, soils, and climatic conditions.

Irrigation has developed in many semiarid areas such as the Southern High Plains to the point where water use has exceeded replacement and reserves are diminishing.

In the humid areas erratic rainfall distribution, water losses from seasonally excessive or high intensity rains, low water holding capacity of soils, and peak moisture demands by crops combine to make irrigation desirable or necessary for many crops. Also, increases in production costs, largely for off-farm items, combined with the need for more efficient production practices demand high yields each crop year. This is especially true with high-value crops. Shallow crop root zones and irregular topography in part of the humid area reduce the possibility for wide-scale land leveling for surface application of irrigation water. Inhospitable root environment in the subsoil sometimes limits rooting depth and proliferation and necessitates supplemental irrigation. At the same time rainfall following irrigation often reduces the effectiveness of applied water and causes drainage problems.

Periodic cursory project-wide evaluations during the past quarter-century have shown that irrigation water is not managed efficiently in most cases. General recommendations for improving farm irrigation efficiency are available and have been advocated for years, but they have not been implemented. Recent detailed studies have shown that irrigation applications are erratic in time and amounts even though commercial soil moisture measurement instruments have been available for years, and in spite of educational programs which have been in effect for an even longer period of time. Part of this problem can be attributed to lack of water control by the farmers. However, simple water control and measurement structures are not available or are not being used. Some soil moisture instruments are too delicate or require too much attention. Labor for water application is less available than in the past or too expensive in relation to water costs.

Irrigation management services provided by an irrigation district to member farmers, are being adopted with enthusiasm and positive results in some areas. These services, however, require much more reliable estimates and predictions of evapotranspiration, allowable soil moisture depletion levels for various crops and soils, techniques for monitoring soil moisture, and plant nutritional status, guides to control or stabilize intake rates with surface irrigation, and facilities for more precise water control than with the older hand methods. In order to adopt improved management services the farmers will need facilities to measure and control water remotely or automatically with less labor. Labor has dominated many farmer decisions. The trade of "skilled irrigator" is virtually unheard of today because it has required long hours and hard manual labor. Remote control, automation and monitoring sensors can enable the farmer to skillfully irrigate his own acreage or attract skilled labor. However, present automated systems are overly complex; they need to be simplified for economy of labor and reduction of maintenance.

Sprinkler irrigation has developed rapidly because this system provides better water control, but hand moved systems also require much labor. In some cases, solid set systems are practical. With automated, self-propelled systems, soil moisture control within narrow limits is possible now, but responses of plants in terms of yield quality and quantity under nearly constant soil moisture levels are not known. Fertilizer practices also change under these conditions because leaching or excessive soil wetting can virtually be eliminated. Some microclimate control in the plant-air zone in addition to soil moisture control such as complete elimination of afternoon wilting is possible with automated sprinkler irrigation, but the extent or advantages and disadvantages of such practices are not known.

Irrigation with water quantities in excess of crop needs, apart from the question of water use efficiency, results in removal in solution of salts and nutrients. Controlled salt leaching may be desirable, or even mandatory, to maintain a favorable soil-water environment. Nutrients leached are a loss to the farmer and may add to pollution of ground and surface water supplies. The contribution to pollution from irrigation, and its relation to irrigation efficiency, is not well documented. Limited data available indicate significant problems in some cases, and absence of a problem in others.

Need for research

The large and inefficient use of water by irrigation makes research towards increased efficiency of prime importance in the framework of a national water resources program, as stressed by COWRR. To obtain significant increases in efficiency requires development and adoption of automated irrigation schemes that enable optimum water application scheduling with a minimum of labor.

Recent emphasis on water quality requires reassessment of present fertilizer-irrigation practices. The extent to which irrigation practices add to water pollution must be established, and the effect of management schemes evaluated in terms of effectiveness of nutrient utilization as well as its relation to water quality.

In those areas--such as the High Plains of Texas--where at present irrigation is mining the available water supplies, there is need for further development of management practices that use available precipitation and supplemental water to the fullest extent possible. Such studies must complement those on increasing the available water supplies described in section 2 of this report.

To enhance more rational water application schemes requires the development of simple and reliable water measurement structures that lend themselves to routine on-the-farm use.

Many other problems can be identified that need solution before optimum water utilization can become a reality. Some sprinkler systems do not yet provide uniform water distribution. Underground systems clog by mineralization. Prediction of infiltration rates, especially in relation to land grading, leaves much to be desired.

Estimating evapotranspiration rates, determining allowable soil moisture depletion levels for various crops and soils, techniques for monitoring soil moisture--these are some of the areas where improved technology is needed to improve present efforts to provide effective irrigation management services to irrigators.

Economic evaluation of the many alternative types of modern systems is needed in terms of labor requirements, water efficiency, capital requirements and per unit costs in relation to outputs.

COWRR has stated that "Because irrigation agriculture is the heaviest water consumer in the U.S...research...should be increased substantially over the next decade to about three times the present effort."

Objectives

The general purpose of research on irrigation is to develop and evaluate methods, equipment, and facilities for efficient water use in irrigation under all com-

binations of crops, soils, and climates in the United States. The specific objectives addressed to important irrigation problems, and the questions which must be answered in achieving the objectives, are elaborated below.

A. On-farm problems

1. Develop criteria for determining the optimum irrigation method.
   Answers are needed to questions such as:
   a. How can water intake rates and desired duration of irrigation set be made compatible?
   b. Are surface irrigation systems economical and practical in semihumid and humid areas and how can they best be combined with drainage systems?
   c. How can surface water application systems be managed to help control salinity?
   d. What plant diseases are most prevalent under the environment generated by sprinkler systems and how can they be controlled?
   e. What soil and climatic conditions permit water table control systems to provide adequate irrigation?
   f. To what extent can sprinkler systems control microclimate?
   g. What is the effect of microclimate on yields?
   h. What are the irrigation systems design requirements for specific crops?
   i. How can evaporation be reduced for various systems?
   j. What are optimum designs for solid set systems and center rotation systems?
   k. What are the relative labor requirements, capital requirements, operating costs, and crop yields under various systems of gravity, sprinkler, and subsurface irrigation?

2. Develop strategies that will optimize returns from water that is limited in amount and time of delivery.
   Answers are needed to questions such as:
   a. When and how should limited irrigation water be applied to minimize evaporation and maximize crop yields?
   b. What are the effects of water deficits on plants at various stages of plant growth?
   c. To what extent can crop quality be significantly improved by greater control of soil moisture and the microclimate of the crop canopy?
   d. What are the effects of excessive water application or rainfall on plant growth?
   e. How can weather and precipitation forecasts be used more effectively in scheduling irrigations to maintain crop quality?
   f. What procedures may provide for accurately estimating evapotranspiration for major variations in climate, geography, and other related factors?
   g. How can water reuse systems be adapted to water-short areas?

h. How can subsurface systems be made more feasible for continuous operation and increased efficiency of irrigation water use?
i. How can membrane systems for control of deep percolation and subsurface water application be made useful for increasing water use efficiency?
j. What is the economically optimum strategy for using a limited irrigation water supply on a given farm under various climates and soils?
k. What are the possibilities of changing air temperatures by sprinkler systems for both heat and frost control?
l. To what extent can surface irrigation be used to prevent frost damage on crops like corn and sorghum?

3. Improve water measurement and control devices and reduce labor requirements for irrigation.

   Answers are needed to questions such as:

   a. Why aren't water measurement devices more readily accepted by irrigation farmers and why isn't water measured as seed, fertilizers, feed, sprays are measured?
   b. Why aren't more remote controlled or automatic structures used for controlling irrigation water?
   c. How can labor requirements be reduced?
   d. Why are some automatic systems abandoned after several years?
   e. How can integrating or totalizing water measurement devices be made practical for open channel flow?
   f. How can automatic or remotely controlled irrigation water structures be made to be fail-safe and require minimum attention?
   g. How can irrigation be managed to reduce water pollution?

(Reference is made to other sections in this report which bear on the above topic: 5 - Improving water control and measurement structures
7 - Removing excess water from soils
9 - Increasing efficiency of salinity control and management
10 - Optimizing water use by plants

B. Off-farm problems

1. Develop and analyze alternative water storage systems within regions.

   Answers are needed to questions such as:

   a. What are the most practical mixes of surface, subsurface, and in-transit water storage systems for appropriate physiographic or water basin regions?

2. Develop and analyze alternative water distribution systems within regions.

   Answers are needed to questions such as:
   a. What are the advantages of underground versus above ground distribution lines, in terms of land used, weed control, and cost (both inter- and intra-farm)?
   b. Development of water metering devices.

3. Develop and analyze alternative water allocating systems.

   Answers are needed to questions such as:
   a. What are the most useful economic criteria for rationing irrigation water between farms? Between types of users? Between regions?
   b. What are the most useful institutional (legal and organizational) types for allocation of water between users?

Potential benefits

Character of benefits

Agricultural production will be stabilized in humid areas by irrigation, the quality of crops can be controlled in all irrigated areas and net returns to the grower should be greater, water pollution from agriculture can be controlled, water resources will be utilized more effectively, and labor requirements will decrease.

Magnitude of benefits

Agriculture is the largest user of water with the nearly one-half of the present use representing evaporative losses in contrast to less than 10 percent consumptively used by industry and municipalities. Irrigation in the United States totaled over 44 million acres in 1965. Nearly 40 million acres are in the 18 arid and semiarid Western States. The remainder is in the humid area.

1. Arid and semiarid areas.
   a. Benefits as a result of practices to increase crop quality and quantity. An increase of 20 percent in crop yields and a 10 percent added farming cost may be expected from use of the improved practices.
   b. Benefits in water saved. A 20 percent saving of the 30 million acre-feet now lost to evaporation, deep seepage and tail water during application may be realized.
   c. Benefits from saving in labor by automation of application system. Assuming a reduction from 5 to 2 man hours per acre irrigated per year on 40 percent of the irrigated crop acres in the Western 18 States, a total saving of 48 million man hours per year may be realized.

2. Humid areas
    a. Benefits in increased quality and crop yield by adoption of irrigation practices developed by research equivalent to an increase in production of 30 percent on acres brought under irrigation might be expected. Ten million additional acres might be brought under irrigation.

This total annual potential value cannot be attained without the joint efforts of (1) research, (2) education and communication media, and (3) industry's developmental work. It is not likely that any single group or the combination of any two could be responsible for the indicated benefits. Research might well be credited with one-third of the annual benefits.

Present and projected research effort

Present research effort on problems of increasing the efficiency of irrigation water use is roughly 43 SMY. It is recommended that this research be increased to 90 SMY in FY 1972 and to 140 SMY in FY 1977.

VII Removing Excess Water from Soils

Situation

Drainage of agricultural land has long been recognized as a practice that improves the environment of plants, thereby increasing the efficiency of crop production. Drainage is also necessary for proper and timely tillage, harvesting operations, and disposal of rural wastes. On nonagricultural lands used for highways, airports, and industrial and residential construction, drainage is essential.

According to the 1960 Agricultural Census about 100 million acres of agricultural land (only 500-acre tracts or larger) in the United States has been drained with open ditches and/or by subsurface drains. The majority of these drainage improvements are in the 30 eastern humid states. The National Inventory of Soil and Water Conservation Needs in 1962 indicated that about 100 million additional acres had an excess water problem. While onlly 16 percent of this area is in the 18 arid and semiarid States, this percentage will likely increase with the expansion of irrigated acreage and the need for control of salinity on older irrigation systems. Because of obsolescence and deterioration of old drainage systems more than 50 percent of present systems need replacement by the year 2000. With the addition of new drainage systems on another 60 million acres, the total acreage requiring drainage will be at least 110 million acres.

Need for research

Drainage is needed primarily to create the proper environment for plants either by providing adequate aeration in the soil or for controlling salinity. Tillage, harvesting, and other field operations are often delayed by excess water. The net result is decreased production, loss of crop or loss of efficiency in farming operations. Drainage is essential for proper waste disposal in rural areas and for the disposal of urban wastes where the effluent is spread over the land.

Present methods for designing drainage systems are based largely on experience and judgment. Research information is limited, but where available it is often not directly applicable to a particular drainage system. Optimum drainage conditions for each crop need to be determined at various stages of plant growth, for different climatic regions, and for major soil types. Drainage requirements for salinity control need to be better established for irrigated soils. Present data are limited and wholly inadequate. Such research would be amenable to a regional approach.

Another aspect of the drainage problem involves the probability of occurrence of soil moisture excesses, including surface flooding. Economical drainage systems cannot be developed unless such information is considered in the design.

Development of new materials and installation techniques can greatly reduce the cost. For example, plastic drain tubes and a laser beam for depth control, which are currently under study, enable the installation of drains without trenching at a cost of only 25 percent of conventional trenching methods.

Drainage systems should also be developed for multiple uses, such as for flood reduction, for pollution control, and for irrigation. Such systems will require improvement in present methods for characterizing the soil, including permeability, porosity, chemical composition, morphological properties, etc. For example, measurement of soil permeability by present methods and techniques is too time consuming and too costly to be useful in designing most subsurface drainage systems. Permeability is also one of the most important factors needed for designing rural or urban waste disposal systems.

A new look must be taken at the overall problem of optimum water management which involves drainage. Greater attention should be given to the soil as a water storage reservoir. Practical ways of holding water for later use by the plant or for release into the streams later in the season would increase low flow and contribute to pollution control. During the nongrowing season the retention of more water in the soil would reduce flooding.

Objectives

1. Determine the drainage requirements of crops at various stages of growth, for different climatic regions, and for major soil types. The drainage requirements include the effects of surface flooding or high water table levels, for various durations, aeration of the soil root zone, salinity, and soil and air temperatures. The selection of vegetation to withstand widely varying moisture conditions, such as the shoreline of multiple-purpose reservoirs for recreation, is also involved.

2. Determine the probability of occurrence and duration of soil moisture excesses or high water tables during the growing season for different climatic regions and for major soil types.

3. Develop new techniques for characterizing mineral and organic soils, especially those properties which influence water movement and the water table level in the soil, such as drainable porosity and permeability. Characterization of the soil may be accomplished by direct measurement techniques or by relating chemical or physical properties to internal water movement. Practical field methods which can be used by technicians who design and layout drainage systems are urgently needed.

4. Develop installation techniques that will improve drain effectiveness, reduce construction costs, and increase drainage system life. Drainage effectiveness can be increased by such practices as the development of new materials and methods of drainage. Construction costs can be reduced by development of lower cost materials, improved design, and improved equipment. Economic evaluation of new drainage technology and equipment

should focus on capital and annual costs of various types of drainage systems and effects of drainage on farm output and net income.

5. Determine drainage requirements for ease and timeliness of farming operations. Tillage, planting, and harvesting operations are often carried on during the nongrowing season during which the climatic conditions may be less favorable than during the growing season. Evapotranspiration is normally low during early spring and late fall. Such conditions may necessitate a higher degree of drainage than during the growing season.

6. Develop multiple-use drainage systems that can serve for irrigation, pollution control, and flood reduction. Large, multiple-purpose drainage systems frequently present major engineering, economic, and organizational problems none of which can be solved independently of the others.

7. Develop maintenance procedures for open and closed drains to reduce sedimentation, chemical sealing, and clogging.

Potential benefits

The benefits from drainage include greater efficiency in crop production and harvest both in quantity and quality of cultivated crops and forests, reclamation of poor or unproductive land, improvement of wetlands, and the reduction of pollution problems. Intangible benefits include aesthetic and health aspects, such as elimination of hazards from mosquitoes, improved environment for man and animals, and appearance of the landscape.

The total area that needs to be drained in the United States in the next 30 years is estimated as at least 110 million acres. This estimate includes 90 million acres in humid areas--50 million acres of land with an excess water problem and 40 million acres of currently drained land, which will need redraining during the 30-year period. In the arid and semiarid regions, the acreage estimated to need drainage is 20 million acres. This estimate includes 12 million acres of land with an excess water problem and 8 million acres of redrained land.

Redrainage with new systems will be necessary because of sedimentation, chemical sealing, deterioration, and obsolescence of present systems. Estimated benefits from improved technology in design and methods will result in a reduction of 15 percent in drainage costs and an increase of 15 percent in crop yields. On the remaining 32 million acres of land with an excess water problem, proper water management can greatly enhance the environment for wildlife. In addition, benefits will accrue to recreational use of land, and improved drainage practices will aid in pollution control.

Present and projected research effort

Projected SMY's include the staff needed for the Drainage Principles Center referred to in Senate Document 59, 86th Congress and for economic and related social science research.

	1966	1972	1977
Economical and social	0	2	4
Drainage Principles Center	0	15	20
Others	30	43	66
Total SMY	30	60	90

VIII Managing Wetlands

Situation

Wetlands occupy about 70 million acres of the Nation's land surface. They include swamps, bogs, marshes, wet meadows and tide flats. Most extensive areas are found along the Southeastern Coastal Plain and in the northern portions of the Lake States. It is estimated that the original area covered by wetlands approached 127 million acres before draining, filling, and dredging was undertaken to increase acreages of cropland or to accommodate construction of roads and buildings.

Lands with excess water have potential value for a number of purposes. Wetlands can be managed to produce better crops, grow better trees, provide improved habitat for wildlife, offer recreational opportunities, or supplement deficient water supplies. Although their inherent wetness makes management difficult, wetlands have potential for these multiple purposes if soil-water relations can be improved.

Since 1947, water levels have been altered on about 2 million acres of wetland forests in the South, and this activity is continuing at an undiminished rate. Woodland water management is used to improve community water supplies, produce forage from otherwise nonproductive wetlands, maintain wetland vegetation in natural areas, impound water for waterfowl use, bring open pineland into production, and improve the soil productivity of marginal wetlands. Many wetland forest landowners consider all drainage of wetsites desirable, but this is not always correct. It is necessary to distinguish between sites where water control is beneficial and those where it may be harmful or of little benefit. For example, bottomlands and swamps are highly productive for hardwood timber and wildlife, as well as for crops or livestock in certain areas. Here, water management is generally aimed at maintenance of natural water levels, including some application of water when necessary. While it appears that 3.5 to 4 million acres of wet flats can be improved for pine production by woodland drainage, bays with deep peat soils are not much improved by drainage. Thus, it is necessary to identify the problem and understand the processes involved before undertaking wholesale application of water control measures.

Approximately 15 million acres of peatland are located throughout the northern forested area of the Lake States. Three-quarters of this total can be classified as forest land varying from nonproductive to high-quality pulpwood sites. Although the hydrologic characteristics of peatlands are largely unknown, attempts have been made to use and develop them. Their past history has been one of conflicting objectives--first, unsuccessful drainage attempts for conversion to agriculture, and then, attempts to restore them to their natural state for watershed properties and wildlife habitat.

Currently, land managers look to peatlands for timber production, wildlife habitat, and water production. Use for wildlife involves management plans calling for water control practices, such as flooding and ditching. Use for timber production often requires other treatments to raise productivity. Water production from peatlands has become extremely valuable to a rapidly expanding industry, and to a growing recreation and resort complex. Land management practices need to be developed to maintain the present water resources and to meet the future demands for water.

Water associated with wetlands is the key to many recreation activities, and wetlands are often the headwaters for streams and lakes. Thus, changes in streamflow caused by wetland management may effect downstream recreation. Wildlife and waterfowl are also produced in some wetland forests. In both the northern breeding grounds and southern overwintering areas, waterfowl managers have been experimenting with flooding of wet areas for duck production.

Water itself is an important product of these areas. Demands for water have caused planners to look to headwater wetlands and speculate about their future use as water storage areas. Because of their capacity for holding water, wetlands also act as safety valves assisting in control of erosion and in reducing destructiveness of floods. In some locations they are vulnerable to water control projects as in the case of the Everglades where water levels have been lowered and wildlife habitat endangered by diversion of ground water in south Florida.

Wetlands are equally vulnerable to various forms of pollution. Because of their natural topographic settings, many are prone to accumulate residues flowing from surrounding areas. The Tule-Klamath Lake Wildlife Refuge in California is one of many wetland areas seriously threatened by the use of pesticides on surrounding agricultural lands. And in northern Minnesota, bogs are being viewed as ideal locations for waste disposal.

Need for research

Wetlands are being used now and more intensive use is certainly in prospect. Yet, our knowledge of these uses on the physical and hydrological characteristics of wetlands is meager.

Before these lands can be managed in an intelligent and plan-wise fashion, more information must be obtained about the physical and hydrologic properties of wetland soils. These factors determine storage capacity and amenability to drainage. Storage capacity influences water table fluctuations and the amount of water retained after drainage. Information on hydraulic conductivity, both vertical and horizontal, is needed to determine amount and timing of outflow and seasonal supply changes in wetland soils.

As more is learned about water movement in peat deposits, better use can be made of areas with highly organic soils. In the Lake States, bogland and

organic soils form the headwaters of many important rivers. Their water properties, if better known, would greatly benefit industries and recreation enterprises dependent upon these headwater areas for water.

More attention should also be given to engineering and soil management in wetlands to improve timber production. Needed studies include adaptation and modification of dams, spillways, water control gates to hold prescribed water levels and achieve desired transmission; land leveling, bedding, disking, fertilization, burning, and other measures to obtain prescribed physical and chemical properties for wetland soils. Forest growth is being measured to determine effects of high water tables and responses to drainage. Experimental manipulations with kinds and amounts of forest vegetation are supplying information about how water levels can be raised and soil properties altered to increase the amount of streamflow or provide more moisture for plant growth.

Despite the fact that water is the dominant feature of wetlands, there is only scant knowledge about how it can best be managed. Attempts to alleviate excess water through varying degrees of drainage have been only partially successful. Poor success can be attributed to lack of knowledge about the hydrologic behavior of water in wetlands. In coastal wetlands, peak flows in unknown quantities occur each year. As the land becomes more intensively used, roads, ditches, bridges, and culverts are installed and must be designed to accommodate flood peaks. Lack of data on runoff rates and the associated precipitation makes estimation of peak flows difficult, thus opening the way for costly damage to installations.

Objectives

A. Hydrologic characteristics

1. Develop information about surface runoff from wetland sites, particularly in relation to storm events.

2. Determine evapotranspiration rates as a basis for evaluating the water balance of wetland sites and the seasonal changes resulting from vegetation use.

3. Determine underground water movements to evaluate amounts of water entering and leaving wetland sites through subsurface aquifers.

4. Investigate relation of bogs to ground-water levels and fluctuations in water tables.

5. Develop a model to represent movement of water through wetland watersheds and to predict runoff from a set of input data on other hydrologic parameters.

B. Wetland soils characteristics

1. Measure hydraulic conductivity of peat and other wetland soils to help determine amount and timing of outflow and inflow in wetland areas.

2. Determine water storage characteristics and saturated and unsaturated flow behavior.

C. Guides for wetland management

1. Develop equations to determine ditch spacing and depth from physical properties of peats.

2. Develop water management practices for wetlands that will optimize their use for wildlife and recreation.

3. Improve control devices for transmission of water and regulation of water levels.

4. Examine the natural properties of bogs in relation to their utility as receiving grounds for organic wastes.

5. Determine the impact on wetlands from the inflow of pesticides, fertilizers, and other chemicals used in bordering areas.

D. Economic and social evaluation

1. Measure and compare all benefits from wetlands as a guide for planning management activities such as draining and controlling water levels.

2. Determine the extent of wetlands needed to fill national requirements for recreation, wildlife habitat and maintenance of desirable water regimes.

Potential benefits

Application of techniques stemming from this research can raise the productive capacity of wetland areas. Man could shape wetland forest environments to meet his future needs. More efficient use could be made of water supplies. Opportunities for recreation would be improved by management of water levels better suited to waterfowl, and better access could be provided for hunters. Engineered flooding and drainage could maintain kinds of vegetation needed for cattle grazing and increase levels of pulpwood production. Growth rates of 20-year-old slash pine after controlled drainage indicate treated sites may produce nearly twice as much pulpwood. Combined benefits from application of research-based management techniques can be expected to increase income opportunities for rural residents and result in a general upgrading of regional economies.

Present and projected research effort

Present research effort on problems of wetland management is roughly 6 SMY. It is recommended that this research be increased to 25 SMY in FY 1972 and to 40 SMY in FY 1977.

IX Increasing Efficiency of Salinity Control and Management

Situation

Dissolved mineral and inorganic salts in the water supply greatly affect the usefulness of the water for production of food and fiber, for use in industry and municipalities, for fish and wildlife and for recreation. These substances enter streams and lakes from man's exploitation and refinement of mineral resources, as waste from chemical and other industrial processes, or from solution of naturally occurring salts contacted by water during its movement on or below the surface of the earth.

Of vital importance to agriculture are salts in waters used for irrigation and those in arid zone soils used for dry farming. Salts originate from the weathering of soil and geologic materials and accumulate when water flowing through these materials evaporates. Thus, warm, arid climates and restricted drainage leads to the accumulation of salts in soils and waters.

Other types of inorganic pollutants include metals, metalic compounds and acids, such as sulfuric acid from mines that can cause serious local problems. This discussion is restricted to salinity.

Low concentrations of inorganic salts in soils are essential for plant growth, but higher concentrations reduce growth by increasing the osmotic pressure of the soil solution excessively. Moreover, high concentrations of certain salt constituents may be phytotoxic, and a high concentration of sodium salts relative to calcium and magnesium salts may adversely affect soil permeability and tilth.

Irrigation waters contain amounts of salt ranging from a few hundred pounds to several tons per acre-foot. Thus, salt damage to crops and soils is an inherent and major problem of irrigated agriculture throughout the world. Irrigated crop land in the U.S. has more than doubled during the last 20 years. Today 40 million acres are irrigated in the 17 Western States where salinity is a problem. A 1960 survey showed that nearly 30 percent of our irrigated land was sufficiently salt-affected to adversely affect crop growth and that excess soil salinity was a potential hazard on about half of the irrigated acreage.

Increased irrigation and the accompanying increase in evaporation and transpiration has resulted in an increased concentration of salt in many rivers. About fifty percent or more of the water diverted for irrigation returns to the atmosphere as pure water leaving its salt burden behind for removal in drainage waters if soil salinity control and permanent irrigation agriculture are to be continued. At Imperial Dam, the salinity of the Colorado River

increased from 1 to 1.25 tons of salt per acre-foot during the period 1945-1965, and it is estimated that it will further increase to 1.50 tons or more by 1985. Thus the control of salinity and the maintenance of profitable irrigation agriculture will become increasingly difficult. The increase in salt concentration of surface waters resulting from irrigation not only affects agriculture, but also may have serious consequences for other users.

Supplemental irrigation is increasing rapidly in the humid areas of the U.S. Salinity in these areas is generally not a problem except along the Atlantic and Gulf Coastal areas where brackish water is a ready source of supply. Crop damage results if salt tolerance of the crop is not matched with water quality, although salt buildup in the soil is short lived as the result of normal rainfall during the winter months.

Relatively large areas of salt-affected soils occur in the Plains States with lesser amounts in the Northwest. The frail lands of the Pierre Shale Plains and Badlands Land Resource area are an example. The Bureau of Land Management of USDI has about 45,000,000 acres of this type land under its jurisdiction. These saline upland areas constitute a large part of the native rangelands in eastern Montana and Wyoming and western North and South Dakota. Somewhat similar areas are in north central Nevada and in the Plains States extending to south Texas. The saline areas are interspersed with nonsaline areas and may cover 20 percent or more of the total area. These areas are difficult to improve in that rainfall is appreciably lower than potential evapotranspiration and the potential productivity level is so low that treatment costs have critical economic limitations.

Research at the U.S. Salinity Laboratory, by the various State agricultural experiment stations and elsewhere during the past several decades has provided many tools to help the farmer in coping with salt problems of agriculture.

The principal means of preventing harmful salt buildup and for reclaiming salted-out land has been to establish subsurface drainage and leach out the salts. Means for estimating the leaching requirement have been developed as well as methods for decreasing the leaching time on slowly permeable sodic soils.

Considerable advancement has been made in understanding the physiochemical behavior of salt-affected soils including water movement and retention. The salt tolerance of economic crops varies ten-fold and progress has been made toward understanding the mechanisms of tolerance. The tolerances of many plants to salinity have been determined. The list includes over 15 fruit crop varieties and rootstocks, 18 field crops, 40 forage crops, 20 vegetable crops, and 24 ornamentals. The effect of specific salt constituents on numerous plants has also been determined.

Irrigation, cropping, and land forming practices to help alleviate the salt problem have been developed in many instances. Improved practices for estimating water use and for water management have been developed to assist

the irrigator in reducing water applications, and hence evaporation, which should result in less severe salt accumulations.

Sensors have been developed for inplace measurement of salinity of the soil water and for measurement of the water potential in plants and soils.

Improved procedures have been developed for determining the quality of water for irrigation use although criteria are by no means complete. Criteria are generally expressed in terms of electrical conductivity and the sodium-adsorption-ratio. Additional research is needed in this area.

Need for research

The economic success and permanence of much of irrigation agriculture in the Western U.S. depends upon solution of the remaining saline soil and water problems for the many diverse soil, crop, and climatic conditions existing. While much progress has been made and effective research is underway, there are numerous areas that need additional research attention as well as new problems to be attacked.

The competition for water is such that, increasingly, the question arises whether whether the use of water for irrigation, which often causes degradation of quality of surface and ground waters, is economically justified. Certainly, it will become necessary to determine the most efficient manner of water use for irrigation and reclamation to reduce both total water use and to minimize adverse effects on quality.

The need for additional information on effective management of saline water and soils is by no means restricted to the United States. The potential for increased economic stability through a strengthened agriculture and improved food production in many parts of the world is dependent on development of irrigation and control of salinity.

Objectives

A. Increasing irrigation efficiency for reduction of salt burden

The problem of salinity control increases with the quantity of water used in satisfying evapotranspiration demands. More efficient irrigation water application systems that would minimize evaporation losses from the soil surface would reduce the salt delivery, the leaching water requirements, and the resulting deterioration of water quality for downstream users. Lower amounts of leaching water would also reduce loss of plant nutrients from the root zone.

B. Management of salinity to reduce evapotranspiration

A modest but controlled level of salinity appears to have a depressing effect on evapotranspiration. It could lead to a lower leaching fraction

and hence reduced water quality degradation. Research needs to determine whether this concept has potential for practical use on farm fields.

C. Soil and water management to reduce salinity in reservoirs and ponds

Management practices on lands high in salt should be investigated in relation to the quality of water in a reservoir. Included should be treatments for preventing or reducing the leaching of soils high in salt.

D. Management and reuse of return flows

Since leaching waters are necessary and return flows contain a much higher concentration of salt than the applied irrigation water, systems for final disposal of these salts or for reclamation of the return flows need to be developed to reduce or eliminate the deterioration of water quality for downstream users. The possibility of reusing waters on salt tolerant plants needs further study.

E. Adaptation of plants to high salt tolerance

Some plants have a salt tolerance ten times that of others. Research needs to be started on genetic modification of plants so that a higher saline soil water level could be tolerated. Plants characterized in small plots or lysimeters should be investigated under field conditions.

F. Improved leaching techniques

Conventional drainage systems for disposal of leaching water do not provide a uniform degree of salt removal from the field. New systems need to be developed to eliminate excessive leaching above and adjacent to the tile line and inadequate leaching of the soil toward the center area between lines. Similarly, water percolating through soil in unsaturated flow tends to remove more salt per unit volume than in saturated flow. Can management systems be devised to utilize this principle on a field scale?

G. Reducing the leaching fraction

Because the precipitation in soil of slightly soluble salts (lime and gypsum) added in irrigation water is maximized and the release of salts from soil minerals is minimized as the leaching fraction decreases, control of salinity in the root zone using the smallest leaching fraction consistent with no salinity damage to crops will reduce pollution of stream and ground waters. Research is needed to determine the minimum permissable leaching fraction for various crops and water qualities.

H. Interaction of water quality and soil properties

A great deal has been learned about the effect of salt containing waters on the properties of soils. Yet, the state of knowledge is insufficient to accurately predict changes in soil properties and the subsequent effects on drainage rates, and to plan an irrigation and drainage system so as to take advantage of these changes.

I. Water desalinization

With the development of nuclear-powered electric generating-desalting plants, interest has centered on imaginative food factories. Large quantities of pure water would be produced and used for irrigation. Can this water be used directly on the land without severe adverse physiochemical effects to the soil? Will partial desalting or dilution be required? Can systems be devised for economically desalting drainage water from irrigated lands? Research needs to provide answers to these questions.

J. Soil evaluation

The evaluation of the feasibility of an irrigation project, based on soil properties, water characteristics and proposed cropping, still poses difficulties. The development of better techniques of evaluation would be extremely useful.

K. Interrelation between sedimentation and salinity

There is an indication that the turbulent mixing and abrasion associated with sediment transport in rivers like the Colorado contribute to salt buildup. Research should determine the importance of this source of salinity, its relation to the source of the salt and the benefits from controlling sediment to salt buildup.

L. Systems analysis

The use of water for irrigation involves the choice of one set of alternatives out of many possibilities. Where the goal is maximum utilization of the total resource, there is required a complicated analysis of these many alternatives, based on physical, biological, economic, and social data. The development of analytical tools to help evaluate the choices should enable pinpointing weaknesses in available data (and hence orient research efforts) as well as decision making for the public good.

M. Dissociation of costs and returns

In some cases irrigators will have little economic incentive to reduce salinization because the benefits accrue to others, such as the downstream users. More information is needed on the economic magnitudes

represented by the damage to downstream users because of salinization, the legal aspects of such damage, and alternative institutional means of dealing with such damage, such as taxation of those causing the damage.

Potential benefits

The benefits of successful completion of research outlined above would be in (a) reduced cost of production possibly up to 15 percent; (b) increased crop yield of 25 percent or more; (c) reduced crop loss on nonirrigated lands by 20 percent; (d) enhanced per acre value of salt damaged irrigated lands by 30 percent; and (e) enhanced water quality for use by rural communities and industry.

Present and projected research effort

Current input by USDA and the State agricultural experiment stations is 26 SMY per year. This should be increased to 50 by 1972 and by 1977 to 75 if a reasonable degree of progress of the research is to be attained.

X Optimizing Water Use by Plants

Situation

The main object of soil-water-plant relations research is to lead to management practices--whether in arid, semiarid, or humid areas--capable of optimizing use of water for plant growth and crop production. In arid or semiarid regions, irrigation permits intensive agricultural operations where food and fiber could not otherwise be produced in sufficient quantities. In less arid climates, irrigation and at times other water management practices may assure the farmer that his crop yields will not suffer from a moisture deficiency and that he will obtain maximum benefits from other cultural operations such as fertilization.

Water management needs and practices necessarily vary widely. Lack of understanding of soil-water-plant relationships and the resultant lack of water management and irrigation principles of broad application have greatly complicated the development of sound water management practices in water deficient areas and particularly have hampered both the planning of new irrigation projects and the operating of existing irrigation areas with necessary efficiency.

In many agricultural areas including many modern irrigation projects, farmers continue to follow water management practices and irrigation programs in accordance with age-old traditions using equipment and practices little influenced by modern science and technology. Irrigation was practiced extensively by the earliest civilizations known. Much of this irrigated agriculture ultimately failed because of technical problems created by incomplete planning and misuse of water and soils. These problems included the application of insufficient irrigation water under conditions where salts could accumulate or the application of excessive depths of irrigation water which leached out soil nutrients, caused ground water tables to rise, and ultimately caused the accumulation of toxic salts. Unfortunately, these same problems continue to cause the failure of some recently established irrigation projects, reduce crop yields far below potential productivity, and create economic and social unrest which so often accompanies fully developing and unproductive irrigation projects. In some areas food production lost through deterioration of irrigated lands is estimated to offset production from additional lands being brought into production under new irrigation schemes. Also of growing importance is the deterioration of man's environment arising from misuse of water. In some areas excess irrigation water accumulates causing drainage problems; or such water, when carried into surface or ground water supplies, may contain soluble plant nutrients applied in fertilizers or chemicals applied for pest control, contaminating our water supplies with substances dangerous to man and many other forms of life.

A recent report of the Food and Agricultural Organization of the United Nations suggest that: "...improved water management (including irrigation and drainage practices) can probably do more toward increasing food supplies and agricultural income in irrigated areas of the world than any other agricultural practice." Continued research on water-soil-plant relationships, if properly integrated and summarized, could transform irrigation from an age-old art into a modern science capable of providing the basis for productive irrigation projects and for greatly improved efficiency in water use.

Efficient water management requires that practices be specifically tailored to meet given conditions. One important aspect of science is the ability to predict what can be expected in given situations. Mankind in general, and particularly the less-developed countries, can ill-afford the time-wasting, resource-depleting and disappointing process of trial and error and inadequately designed local trials. Continued research and utilization of this research is needed so that most developed and developing countries can more adequately estimate the crop irrigation requirements, predict the effects of specific irrigation practices and related farm operations on given crops under prevailing site conditions, and develop cropping and management systems capable of optimum yields and water use efficiency.

The gross effects of deficient and of excessive soil water on plant growth are well known, but there has been much controversy about specific water management practices required to produce a desired level of crop production. In irrigated areas, some specialists have advocated relatively infrequent irrigation, while others have favored keeping the soil quite wet. Many agriculturalists irrigate with unnecessary frequency and with a great waste of water--thus, leaching plant nutrients and aggravating drainage problems.

Since water, especially in the arid regions, is a limiting and usually a costly resource, it is generally desirable to plan water management programs for "efficiency" in terms of maximizing crop yield per unit of water used. In some cases, it may be preferable to maximize crop yield per unit of land or per unit of initial investment in land preparation or irrigation distribution systems. Thus, the most desirable water management practice will vary with the situation and depend upon proper integration of all factors involved. Practices to be recommended should be based upon thorough knowledge of water-soil-plant relationships and should be designed specifically in accordance with prevailing soil, crop, climatic, management, and economic factors.

Water management practices should not be merely copied from practices reported as successful elsewhere without carefully comparing all factors involved. Especially in arid regions, it should be emphasized that a totally successful irrigated agriculture and the efficient use of limited water supplies requires that the irrigation, fertilization, and other cultural practices all be adjusted carefully to match local conditions.

Research on water-soil-plant relationships and resultant water management practices reveals many opportunities to influence the development of crop plants so as to best serve man's needs and to increase production per unit of available water. Such research on water relationships is needed to supply basic information required for water resource allocation and to set up and operate modern farm management systems increasingly necessary for efficient operations especially in arid regions.

Need for research

Worthwhile possibilities for reducing water requirements include use of better adapted crops, the selection and improvement of varieties, and improved cultural practices. Since evapotranspiration is chiefly dependent upon climate, it is apparent that short-season crops require less water than long-season ones, other conditions being equal. Shortening the required cropping season by one week during dry summer months could reduce evapotranspiration and the water requirement by at least two inches. Research on water-soil-plant relationships indicates that some crops are relatively insensitive to soil-water depletion because of differences in inherent physiologic behavior, nature of the root system, or other factors. A crop such as alfalfa, which can deplete deep stored soil water without adverse affects on yields, will generally have lower irrigation requirements during an equal time period than one such as ladino which has much shallower roots. Also differences of susceptability to attacks of diseases and insects which limit rooting depth in turn affect irrigation frequency and thus the efficiency of water use by different varieties. Some plant species inherently have a relatively low transpiration rate or the ability to survive a little damage during water stress periods. Such species have been sought as means for increasing water use efficiency in the production of food and fiber. This apparently attractive approach may lead to disappointment if it is not recognized that such relatively drought-resistant plants may also have very slow growth rates when under water stress and thus may produce only low yields without irrigation.

Although there has been relatively little work done to breed increased drought resistance into crop varieties, much progress has been made in adapting species to arid environments. Breeding in cold tolerance, for example, would permit crops to be planted during the cooler season of the year or in cooler areas where evapotranspiration rates are lower. Geneticists have also sought to breed varieties that more nearly fit into the rainy season of given areas. Decreasing the length for the growing season required for favorable yields also is an important means of increasing water use efficiency. Other possibilities include the breeding of varieties that will remain green under high water stress.

Certain crop cultural practices deserve consideration as the means for reducing water requirements. These include the adjustment of planting dates to permit plant establishment and root development during cool weather, to avoid high evapotranspiration rates in midsummer, and to shorten the growing season.

Row direction, plant spacing, and other geometric factors offer possible means for controlling evapotranspiration by altering interception and disposition of incident radiant energy. Weed control in crops is also important since evapotranspiration is generally increased by weeds growing in the crop, especially in rows with wide row spacing. The use of cover crops in orchards and vineyards may be open to question in water-scarcea areas. Such covers do increase evapotranspiration appreciably, and this additional use of water may outweigh the beneficial effects in terms of erosion control, improved soil structure, and plant nutrient supply. Cultural operations designed to maximize the retention of precipitation falling during the non-crop period or during the growing season can also be of great importance. The use of plastic films to cover a portion of the soil surfaces show possibilities for reducing evapotranspiration and increasing crop yields per unit of available water. Also of great importance is the provision of all practices and inputs which will increase crop production per unit of growing time. Thus, the timely application of proper fertilizers and pesticides can have very great effects on water use efficiency. Attention should also be given to a timely harvest of crops so as to decrease unnecessary use of water during the maturation period.

Less than one percent of the water absorbed by plant roots is retained in the harvested crop. This means that 99 percent of the water taken up by plants is lost to the atmosphere. Thus, in comparison with water losses on watersheds, in storage, in conveyance, and in irrigation application, the plant itself actually constitutes the least efficient step in the conversion of precipitation into harvested crops. This presents the research scientist with a tremendous challenge on which some work has begun. There appear to be possibilities for controlling the stomata (the small openings through the plant leaf surfaces through which the plant receives carbon dioxide and loses water vapor) by the use of chemicals which specifically affect the stomatal mechanism. Possibilities are being explored of coating the leaves of plants with plastic film which is relatively impermeable to water vapor, but transmits light and carbon dioxide. Another interesting possibility is the application of materials which increase the reflectivity of leaves thus reducing the energy available to evaporate water.

The very low efficiency in converting water to crops presents the research scientist with exciting challenges which can have substantial effects on crop production and the efficiency of water use. For example, the pineapple plant uses less than one fifth as much water (per unit of dry matter produced) as required by principal crops. Can the special xerophytic characteristics and unique metabolic system of the pineapple be incorporated into other crops? Can Plant Physiologists and Plant Biochemists synthesize materials which may alter the drought resistant characteristics of plants and their abilities to grow under water deficit conditions? Can antitranspirants more effectively waterproof leaves minimizing water loss but not undesirably affecting the plant growth? On the other hand, in some situations man may wish to use plants to draw surplus water from soil in

order to eliminate undesirable consequences of marshy conditions or to permit growth of desired plants intolerant of wet conditions. For such situations, man will want a plant which will tolerate surplus water and transpire actively.

Problems mentioned above and many more challenge scientists, engineers, and others involved in achieving optimum functioning of the water-soil-plant system. These represent some of the challenges which man must face and find answers for if he is to accommodate, with acceptable standards of living, the growing population of the planet. Can man alter the geometry of plants so as to increase leaf area which is effectively illuminated or alter the metabolic processes within these leaves so as to increase the efficiency in conversion of radiant energy into photosynthates?

Objectives

To meet the above challenges requires continuation of present research and new research in the following areas:

A. Selection and breeding of crops for reduced water requirements.
Would include seeking plants with greater resistance to water loss (i.e. greater xerophytic characteristics), greater tolerance to cold or other climate conditions as necessary to permit planting during seasons where evaporation conditions are less severe, shorter growing season, and higher yields per unit leaf surface.

B. Increased photoxynthetic efficiency of plants.
In addition to plant selection and breeding, possibilities include research directed to altering plant leaf geometry, population and spacing, and directions of planted rows so as to optimize leaf illumination. Other possibilities include enriching the carbon dioxide content of air surrounding plants and altering the metabolic steps involved in photosynthesis through a better understanding of the biochemical and enzymatic processes occurring in plant cells.

C. Controlling water loss from plant surfaces.
The very low efficiency (less than 1 percent) with which plants convert water to crop constitutes a tremendous challenge. Development of anti-transpirant materials or other methods to reduce transpirational loss of water could have a number of important benefits such as:

1. Saving of stored soil water or irrigation water.
Preliminary research indicates possibilities of reducing transpiration by 25 to perhaps 50 percent. Such reductions in water requirements could have tremendous effects in agriculture both in rain-fed and irrigated agriculture. In irrigated areas such materials, if successful, could permit substantial expansion of cropped areas without resort to expensive new water projects or

could allow release of some water now required by agriculture in order to meet growing demands from other users including domestic and industrial.

2. <u>Extend climatic range for favorable crop growth and yields.</u>
In arid and semiarid regions, partial desiccation of plants even during relatively short periods may prevent successful production of some important crops. An effective anti-transpirant, by protecting plants from excessive water loss, could permit favorable growth and yield of these crops in areas now unsuitable for the unprotected plant.

3. <u>Reduce physiological disorders arising from desiccation.</u>
Some disorders in important crops appear to be caused by excessive water loss. Antitranspirants may provide an effective means for combatting this problem.

4. <u>Reduce salt damage.</u>
Serious losses occur yearly in arid and semiarid regions from salt accumulation in crop and ornamental plants. Severity of injury generally increases under conditions of high rates of water loss from leaves. Antitranspirants, by reducing leaf water loss, may be effective in reducing salt uptake by plant roots thus minimizing plant damage and possibly permitting satisfactory plant growth with water of relatively poor quality and with use of less water for leaching.

5. <u>Improve crop yields and/or quality.</u>
Antitranspirants by maintaining a more favorable water balance within plant tissues may be expected to increase yields of crops now adversely affected by periods of partial desiccation. Improved quality, especially where dependent upon size or turgor of the harvested crop, may also be possible.

D. <u>Regulation of plant growth and yield by water management.</u>
Water stress may influence initiation of flowering and subsequent set of fruit and its maturation. By controlling soil moisture through irrigation, evaporating conditions by sprinklers, water balance in plants by use of antitranspirants, man may be able to influence the development of crop plants so as to maximize that aspect of plant growth desired for harvest.

E. <u>Water management in relation to mechanical harvesting and crop processing.</u>
Little attention has been given to possibilities of expediting mechanical harvest by controlling initiation, peaking, and setting of flowers and by controlling rates of crop maturation so as to maximize fraction of potential yield available for harvest at one time as normally required for efficient use of harvest machines. In some cases water management may be useful to spread maturation dates between fields thus permitting

use of one machine on a greater area and reducing peak loading on transportation and processing.

More study is needed on relations between water stress and the tolerance of crops to bruising in mechanical harvest, transportation, and processing. Water stress may have important effects on crop quality, storage life, and on its suitability for processing.

F. Water management in relation to disease and insect control.
Intensive irrigation programs as now practiced in an effort to achieve maximum yields complicates disease and insect control. Particular attention should be given to relations between irrigation and incidence and control of root rots.

G. Prediction of relations between levels of water supply and plant growth (production functions).
Modern techniques of systems analysis, together with detailed experiments required to produce essential data, will allow development of relations between crop yields and levels of water supply as influenced by climatic condition and levels of other inputs including fertilizer. The availability and use of such production functions could substantially increase water use efficiency by optimizing water allocations among conflicting uses and areas of use. Optimizing land areas to be irrigated and crop planting programs, and optimizing use of water for such operations as periodic or deferred leaching for salt control.

H. Cropping and water management problems for specific water supply situations.
Worthwhile opportunities exist in most agricultural areas to effect gains in crop production and/or water use efficiency by following cropping and water management programs tailored to specific situations. The development of such programs requires a systems approach to optimizing all production factors and inputs using modern analysis techniques. Application of these modern programming methods is lagging in agriculture and should be given much greater emphasis. This research requires teamwork of systems specialists and scientists familiar with crop and pertinent production factors.

Factors to consider include choice of crops and varieties, planting dates, and populations, levels of production inputs, and all cultural practices. Since a plant exposed to radiation will use water by transpiration whether or not it is making favorable growth, any factor which limits growth will decrease water use efficiency. Particular attention needs to be given to interrelations between water use efficiency and such production factors as fertility level, salt balance, temperature control, and crop protection. Selection of an optimum water management program necessarily must consider seasonal water requirements of different crops, seasonal distribution of available water supplies, desirability of off-season irrigation for root zone water storage and/or ground-water

recharge, desirability of providing for leaching and/or ground-water recharge during cropping season, strategy for optimal use of a deficient water supply, and cropping and management practices for most efficient use of a nearly constant water supply as arising from waste water treatment plant or multipurpose desalinization plant.

Potential benefits

The growing and increasingly conflicting demands of agriculture, industry, and domestic users for limited supplies of water necessitates increased water use efficiency by all users. Since irrigation agriculture diverts about 40 percent of water used for all purposes nationally and as high as 90 percent in an arid region such as California, agriculture must accept major responsibility to achieve greater efficiency in its use of water.

Successful completion of research proposed on water-soil-plant-relations would benefit all segments of American society through increased efficiency in water use and crop production. It is difficult to put a realistic dollar value on water saved through more efficient agricultural use since the price of water is often unrelated to its real value to users.

Farmers

Would benefit as a result of:
1. More water available for irrigation of additional land.
2. Reduced costs of production especially in areas of high-cost water.
3. Increased crop yields and quality per unit of water with appropriate attention to economic factors.
4. Greater profit from farming operations.

Industry

Benefits would include:
1. Increased availability of water in water-short areas where agriculture now diverts essentially all of the present supply.
2. Opportunities in the food processing industry to spread peak loads by spreading harvest operations by farm crop and water management combined with management of other production factors, and to reduce processing losses by delivery of farm products of better quality and resistance to damage in handling and storage.
3. Greater demands by agriculture for production inputs including processed seeds, fertilizer, pesticides, transpiration retardants, and possibly other special products such as growth regulators and other materials altering metabolic processes in plants.

General public

In addition to above benefits, the American public would have an increased opportunity to at least maintain or possibly achieve better living conditions

by reducing constraints of limited supplies of water and of the products of farm and industry.

Education of future water scientists and engineers.

Research proposed will provide training and guidance for water specialists who will become increasingly vital as man must find ways to accommodate more human lives per unit of water while maintaining acceptable standards of living.

Full use should be made of the research facilities of universities by encouraging such programs as Cooperative Regional Research in order that maximum advantage be taken of the educational values obtainable as by-products from conducting the proposed research.

Present and projected research effort

Current input by USDA and the State agricultural experiment stations is 25 SMY per year. This should be increased to 55 by 1972 and to 90 by 1977 if necessary progress in meeting these important needs is to be achieved.

XI Controlling Water Erosion and Sediment

Situation

Erosion by water is the dominant conservation problem on 179 million acres of cropland and about 32 million acres of non-Federal pasture and rangeland on the U.S. mainland. Erosion on construction sites and related developments in urban areas, and areas in transition from rural to urban industrial uses, is a problem of growing national concern. Erosion control on Federal and State highway systems and on railroad and utility rights-of-way require the expenditure of large sums of money. Erosion along country and private roads is frequently a major and unresolved problem.

Erosion results in drastic losses to a precious natural resource--the land. It results in reduced efficiency of farm operations and reduced crop yields. It results in tremendous losses of plant nutrients, and hence soil fertility. The efficiency of water utilization is reduced and in some cases, as illustrated by the once highly productive Brown loam soils of Mississippi, the use of the land for agricultural purposes is seriously limited.

Erosion is the source of sediment which impairs the quality of the water resources in which it is entrained and frequently degrades the location where it is deposited.

Sediment, a product of erosion, becomes a pollutant when it occupies water storage reservoirs, fills in lakes and ponds, clogs stream channels, settles on productive lands, and interferes with their use, destroys aquatic habitat, creates turbidity that detracts from recreational use of water, as well as when it degrades water for consumptive or other use, increases water treatment costs, or damages water distribution systems. In addition, sediment is a carrier of other pollutants, such as phosphates and some pesticides.

Separation from their sources of the varied eroding materials that become sediments may be accomplished by gravity, frost-heaving, temperature expansions and contractions, raindrop splash, scouring wind and running water. Activity of these natural agents is increased by the numerous activities of man that remove the protective cover and disturb the soil, or change the dynamic equilibrium of a river. Transport of the separated particles may be by wind, water, or gravity. This chapter is concerned with erosion caused by water and the resulting sediment.

Sediment derived from land erosion constitutes by far the greatest mass of all the waste materials resulting from agricultural and forestry operations. Committee Print No. 9 of the Senate Select Committee on National Water Resources states:

"Rough estimates of the suspended solids loadings reaching the Nation's streams from surface runoff show these to be at least 700 times the loadings caused by sewage discharge."

In an average year, approximately 450 million cubic yards of material are dredged from U.S. rivers and harbors in order to maintain the navigation channel. Much of the material removed is sediment.

Erosion by surface runoff produces some 4 billion tons of sediment each year, and of this total, one-fourth is transported to the sea. About three-quarters of the sediment comes from agricultural lands.

Sediment may come from forested lands that have been devastated by fire, construction of forest roads and other forest improvement, certain logging practices, over-grazing and trailing of animals on rangelands, cultivated lands that are improperly treated or inadequately protected, industrial construction sites, highway construction, unprotected roadside cuts, suburban development projects, spoil banks from strip mining and other mining activities, unstabilized streambanks, and natural erosion of such areas as the Badlands of South Dakota. The land is robbed, and the water despoiled.

Erosion from cropland is the most significant single source of sediment and constitutes the greatest single cause of loss. Sediment production from a construction site may be spectacular and of extreme local importance, but such incidents make up a small percentage of the total sediment burden of our rivers. Of the 17 million tons of nutrients flowing down the Mississippi annually, a large share originates on agricultural land. Yet other important sources must be considered and some are described briefly.

Erosion along highways: Erosion along primary, secondary, and tertiary highways is extremely active where protection from it has not been provided. During highway and road construction activities, the land surface is vulnerable to erosion. It has been shown that such disturbance in Scott Run Watershed, Fairfax County, Virginia, has produced sediment at the rate of some 89,000 tons per square mile per year at the source and about one-half this amount was measured downstream at the gaging station. The average sediment yield for an average storm event in highway construction areas was found to be about 10 times greater than for cultivated land, 200 times greater than for grass areas, and 2,000 times greater than for forest areas. Erosion losses measured from bare roadside cuts near Cartersville, Georgia, ranged from 185,000 tons per square mile per year to 27,500 tons per square mile per year depending upon the rainfall, the degree of slope, and the exposure of the bank. Comparable rates were found on roadcuts in the Baltimore area.

Erosion from areas undergoing construction: Construction activities involved with urbanizing areas give rise to similar rates of sediment production. Rates per unit area vary tremendously depending upon the size of the drainage areas. On a small construction site at Johns Hopkins University, encompassing about 1-1/2 acres, a sediment yield rate of 140,000 tons per square mile per

year was measured. To illustrate the high sediment yields from areas undergoing construction, the watersheds of Lake Barcroft, Virginia, and Greenbelt Lake, Maryland, contribute peak sediment yields of 25,000 tons per square mile and 10,000 tons per square mile annually, respectively.

Streambed and streambank erosion: Erosion is a serious problem on at least 300,000 miles of the Nation's streambanks. Because the banks of the streams and rivers are essentially a part of the water and sediment conveyance system, material eroded from these banks is immediately available as damaging sediment. Recent surveys of the intermontane region of the Western United States indicate that 66 to 90 percent of the sediment production of many of the streams comes from streambank and streambed erosion.

Strip-mined lands: Approximately 2.3 million acres of sediment producing surface or strip-mined lands exist in the United States and are critical sources of sediment and other mine wastes. The greatest portion of these many acres is abandoned with little or no provision available to apply the basic reclamation measures needed to alleviate the conditions that are contributing to the detrimental off-site conditions, or again make them into a useful resource. Studies made in southeastern Kentucky indicated that sediment yields from coal strip-mined lands can be as much as 1,000 times that of forest. During a 4-year period, the annual average from Kentucky spoil banks was 27,000 tons per square mile, while it was estimated at only 25 tons per square mile from adjacent forested areas.

Storage capacity of reservoirs: Storage capacity of artifical reservoirs in the country is being depleted at the rate of about 1 million acre-feet each year by the deposition of sediment. This damage is reflected not only in the loss of storage capacity for water supply, flood control, power generation, navigation and regulation of streamflow for water quality control, but also in its impact on these facilities for recreation.

The useful life of many farm ponds is surprisingly short because of sediment accumulation. Surveys on 30 farm ponds in the Iowa and Missouri Deep Loess Hills land resource area showed that, on an average, they would be completely filled with sediment in 20 years. However, the ponds will have been rendered essentially useless, and many will have become a nuisance long before their original water storage capacities have been replaced by sediment.

Loss of reservoir capacity to sediment has particular implications for programs of water resources development because reservoir sites are limited. Indeed, prevention of such losses is a primary justification for land treatment measures and watershed protection programs in many upstream tributary areas of the country.

Recharge of aquifers: The presence of suspended sediment in water being used to artifically recharge underground aquifers presents problems by clogging the aquifer pore spaces, and costs are incurred to clear the water before it can be used for this purpose.

<u>Other effects</u>: Aside from filling stream channels, irrigation canals, farm ponds, and reservoirs used for irrigation, recreation, fishing, and farmstead water use, sediment in water increases the expense of clarification of the water used on the farmstead or in sprinkler irrigation systems. Suspended sediment impairs the dissolved oxygen balance in water and thereby slows amelioration of other oxygen-demanding wastes. Reduced oxygen supply hurts fish life. Fish population is also reduced by the sediment blanketing fish nests, spawn, and food supplies. The thousands of farmers using farm ponds to sell fishing rights are much concerned with the deterioration of water quality by sediment.

The adverse effect of water erosion upon agriculture is by no means limited to losses associated with recreational use of farm and ranch ponds. Damage to agricultural land resources from gullying, reduced productivity of eroded land, overwash of infertile materials, impairment of natural drainage, and swamping and increased flooding because of sediment accumulations in stream channels are also aspects of the erosion problem having a direct bearing on farmers and ranchers. Irrigation canals and waste water disposal ditches are also subject to costly maintenance because of sediment deposited from muddy water.

Potable water must be free of sediment. Many industrial uses, for example, food processing, require sediment-free water. Sediment deposited in condenser tubes used in industrial cooling may cause costly incrustations. Cost of clarifying water increases with degree of turbidity. High turbidity of water adds costs through the need for greater use of chemicals as flocculants, and more frequent cleaning and disposition of silt from settling basins.

People like clean water for swimming and other recreational activities.

Fine suspended sediment has caused heavy losses of commercial fish and shellfish yield from both inland and tidal waters.

Coarse sediment passing through power plants has caused serious abrasion of turbine blades.

Deposition of sediment in stream channels or aggradation of floodplain lands may impair drainage and cause channels to overflow more frequently. Since sediment increases the volume of the flow which carries it, floodflows carrying high sediment loads inundate a much larger area than comparable flows free of sediment. Floodborne sediment may damage growing crops. Sands, gravel, and other coarse debris deposited on fertile alluvial soils may reduce their productivity.

Estuaries, bays and coastal harbors tend to become vast sediment traps where continuous dredging and other operations are required for handling sediment. Commingling of fresh sediment-laden water and saline water, plus the influence of tides, waves, currents, and shipping traffic, complicate the depositional processes in such coastal areas, and we should recognize that sediment is a major contaminant of these areas.

The biological impact of sediment arises partly from the materials transported by sediment: adsorbed toxic and nutrient chemicals, some radioactive materials and some pathogens. Direct adsorption on sediment particles and biologic metabolism of nutrients carried by sediment may reduce available oxygen in water, and so affect aquatic life.

Need for research

Methods of preventing erosion and sedimentation are known and are being applied to some degree to most source areas and causes; however, there remains much to be done to control erosion on crop and rangeland and on unreclaimed mined lands. Although some protective measures are being applied for protection of denuded sediment producing areas in suburban development and in road and highway construction, the rate of expansion of the highway network and of growth of towns and cities is such that we are barely keeping even with the increase in the problem. We are a long way from attaining the reductions in erosion and sediment movement that could be made with present knowledge; even at best we could not expect to stop all of it. We will always have some sediment to contend with; for a long time yet, it will remain a major problem.

In some cases, the limited application of erosion control practices is due to lack of realization of the consequent damages or unfamiliarity with the available techniques. More often, the cause is associated with the costs of control, or the apparent disparity between the beneficiary of and the investor in control measures.

Technology is currently available to permit reduction in the movement of sediment. However, even with the application of current and prospective technology for erosion and sediment control, some sediment will continue to be carried in moving water and will carry with it various available pollutants. It is the fine particles that are the principal carriers, the most active chemically, and transported farthest before deposition. We do not yet have adequate controls for the clay and colloidal sediment fractions, both at source and in final deposition.

Control of erosion at the source is the most direct, and usually the most satisfactory, approach in dealing with most sediment problems. Such erosion control practices are multibeneficial by preserving land and vegetation resources and at the same time reducing sediment yield.

For instance, where the sediment is derived from sheet and rill erosion on agricultural, forest, or rangelands, certain agronomic and forest and range management practices, as well as mechanical and structural measures, effectively reduce sediment yields. Changing cultivated fields from row crops to small grain may reduce soil loss due to sheet erosion by from 60 to 90 percent, depending on cover conditions, soils, and seasonal distribution of rainfall. Rotation of crops to include meadow in the cropping sequence may reduce average soil loss from fields by 75 percent. Such practices as mulching,

strip cropping, and contour cultivation have been shown to be highly effective in reducing soil erosion on farmlands. Graded cropland terraces may reduce erosion on fields by 75 percent and in combination with crop rotations, mulching, minimum tillage, etc., can reduce to practically nothing soil loss from cultivated cropland fields. Converting cropland to good grassland, pasture, or woodland can reduce soil erosion by 90 percent or more.

The conversion of cropland to grassland may result in a reduction in income to the farm operator. Some types of terraces may greatly increase the cost of farming. These examples illustrate the need for development and evaluation of practices that integrate control of erosion with a viable farm production system--conserving the resource, providing reasonable farm income, and reducing damage from sediments.

Another area of concern is the role of sediment in transporting pesticides and other chemicals. Increased interest in managing the quality of the environment has focused attention at the lack of data in this area.

Particular attention should be given to the integration of the use of mulches, vegetative cover, and structures to obtain the most feasible, most acceptable, most effective system of erosion control. For example, waste fibers from logging operations or from agricultural processing plants might be economically converted into cover materials for treating disturbed areas. Also, special techniques and treatments are needed for arid and semiarid areas where establishment of vegetation is difficult as well as for obtaining aggradation of gulleys and washes in desert and semidesert areas.

Prevention of all soil erosion is highly unlikely and possibly not even desirable. Since some sediment production will continue, methods must be devised for handling it. Is it better to provide sediment trapping basins on major streams or should sediment be permitted to flow to the ocean? Can sediment be made useful for developing new lands or for improving present unproductive lands?

Objectives

A. Increase the knowledge of erosion processes to better define the basic principles governing the movement and loss of soil.

B. Develop better concepts and procedures for identifying critical sediment source areas and predicting sediment delivery from such areas as affected by natural and man-induced environmental conditions.

C. Improve and complete criteria for the design of sediment traps and debris basins.

D. Develop improved control practices integrated into systems that will reduce erosion from farm and forest lands that will be feasible and compatible with modern agricultural and forestry techniques for both public and private uses of land.

E. Improve our understanding of the rates and processes of sediment deposition in reservoirs and water detention structures, on floodplain lands and in estuaries and harbors.

F. Develop more effective and economical techniques for stabilizing stream-banks.

G. Develop new technology to stabilize eroding soil in developing urban areas, on roads and highways, and on other construction sites.

H. Demonstrate the feasibility of using grassed waterways, of diverting cropland runoff and highway drainage onto sod-forming crop areas or woodlands; to provide and measure the effectiveness of these organic filters and traps for sediments and other pollutants before the drainage waters reach streams or ponds or lakes.

I. Determine the rate of chemical and biological breakdown of the various kinds of pollutants adsorbed on sediment particles and identify environmental conditions under which the rate of breakdown can be enhanced.

J. Determine the kinds and quantities of plant nutrients carried from agricultural and forest lands in eroded sediments and their organic fraction, and how this loss can be reduced.

K. Identify the kinds and quantities of pesticides and other pollutants carried from agricultural and forested lands in eroded sediment and their organic fractions.

L. Determine the costs of controlling this pollution at the source, while in transit, or at the point of deposition. (There is a correlated need to assess the advantages that would accrue to society by controlling these pollutants at each of these three points in the system.)

<u>Potential benefits</u>

The interest in erosion and its control is twofold. First, unchecked accelerated erosion wastes a natural resource essential for production of food and fiber; and second, its end product--sediment--causes tremendous damages to floodplain lands, urban areas, navigation facilities, downstream reservoirs, recreational developments, aquatic environments; and degrades water quality.

The research will result in more effective means and measures for retaining productive topsoil and mineral nutrients on croplands; topographic modifications for more efficient operations of farm machinery, thus reducing cost of production; preserve soil resources for use when demands for food and fiber increase; reduce cost and increase effectiveness of measures for stream channel stabilization and gully control; reduce cost of construction in urban and other areas; increase safety along highways and reduce costs for erosion control and water disposal systems along roads and highways; enhance natural beauty; slow eutrophication of lakes; and contribute tremendously toward reduction of damages caused by sediment.

Attainment of the objectives cited herein would make it possible to reduce the average annual rate of soil loss from the 179 million acres of cropland on which water erosion is the major problem by an average of at least 25 percent. This reduction, estimated at 0.7 billion tons of soil annually, would save mineral nutrients that would otherwise be lost with the surface soil. Besides being a factor in crop production, the lost minerals would contribute substantially to degradation of water quality downstream and constrbute to accelerated eutrophication of many natural lakes in rural and urban areas.

An estimated 1.5 billion cubic-yards of sediment are deposited in the Nation's artificial reservoirs annually. The erosion control and stream channel stabilization technology to be provided by this research would make it possible to greatly reduce this costly waste. A 25-percent reduction of this sediment deposition would save reservoir storage capacity sufficient to provide an annual water supply for 1.3 million people.

Improved agronomic and soil management techniques and topographic modifications that control erosion indirectly increase crop productivity and reduce the number of acres required to attain equal total product. Savings are possible in labor, machinery operation, seed and fertilizer for each acre taken out of production.

Additional benefits, that are more difficult to assess quantitatively, would include increased recreational and aesthetic values, decreased costs of sewer-system maintenance and sewage treatment, better environment for plant and animal life, and decreases in damage from flooding and deterioration of stream-banks due to loss of capacity brought about by sediment deposition.

Present and projected research effort

Present research effort on problems of controlling water erosion and sediment is roughly 90 SMY. It is recommended that this research be increased to 205 in 1972 and 330 in 1977.

XII Maintaining and Enhancing Water Quality

Situation

Quality of the environment, a major objective of all agricultural and forestry research programs, is of vital concern to every segment of human society. In city or countryside, on land, air, or water--everywhere we face increasing pollution.

The members of the Task Force on Water and Watersheds are aware of the report of the Task Force on Quality of the Environment. They are pleased to endorse the general concepts and evaluations presented in this report. They also recognize that research or action programs directed towards improvement or maintenance of the quality of the environment cannot be separated from programs dealing with the conservation and utilization of resources. Thus, an evaluation of research needs on Water and Watersheds must of necessity concern itself with the question of water quality.

Water quality is an elusive term that defies exact definition in meaningful words. Water quality evaluation must be related to the intended use of the resource, and research related to water quality must consider interactions and alternative uses of the resource as well the consequences of specific management practices. Distilled water may be required in the laboratory, useful although not required as cooling water in industry, undesirable as a fish habitat and harmful to soils when used as irrigation water. A concentration above 40 ppm of nitrate is purported to be harmful for drinking water but may be advantageous for irrigation.

Population growth, industrialization, economic expansion, and unprecedented changes in science and technology are among the factors affecting agriculture and quality of the environment. The mounting evidence of water quality deterioration has caused increasing concern throughout the Nation. Public interest and concern about the quality of water resources resulted in legislation to curtail pollution. Pollutants can reduce or eliminate a resource; for example, quality deterioration can be as effective as a drought in reducing a water supply. Alternative means of alleviating pollution problems must be evaluated to determine if they are in harmony with our physical, biological, social, and economic objectives.

There is an urgent need to develop relevant economic information on the location and severity of water pollution problems, the alternative means of control, and an evaluation of the economic effects. A whole array of decisions must be made if optimal economic and social objectives are to be met. Answers must be sought to questions as: What is the delineation between pollution and non-pollution? What are we willing to pay for specific levels of quality? What are the benefits and remaining damages at specific

quality levels? What are the consequences of established regulations and standards? What is the optimal combination of production needs and environmental requirements? Answers to these and sirilar questions are needed to establish effective legislation or regulation of equitable enforcement of quality.

In one sense, pollution is the price we pay for progress. Few people, if they recognized the full impact, would be willing to get along without the use of pesticides. Still fewer, without automobiles. Thus, one aspect of the pollution problem involves learning to live with it. Finding the balance between adapting to acceptable levels of pollution and controlling or eliminating excessive levels of pollution is no small challenge.

In terms of the consequences of water quality attributes in relation to agriculture, one may distinguish between effects <u>from</u> agriculture and <u>on</u> agriculture, and between <u>adverse</u> effects and <u>enhancement</u>. In general, however, many factors interact so that no clearcut distinction can be made; in water management, the integrated effects and consequences of all such factors must be treated as a system.

The major sources of water pollution of concern to agriculture have been described in the report, "Quality of the Environment." They include the following eight categories.

a. <u>Sediment</u> - Probably the most important single water pollutant, it causes damage in its own right as well as a carrier of mineral and organic substances. It has been treated separately as section 10 of this report.

b. <u>Plant nutrients from soils and fertilizers</u> - Plant nutrients are normal constituents of fertile soils, vital in the production of food and fiber, and frequently augmented by fertilizer applications. As water moves through and over the soil, nitrates tend to move with it. Some of the nitrogen in surface waters that enable the growth of fish, algae, and aquatic weeds originates from fertilizers on agricultural and urban lands. Similarly, nitrates tend to move downward through the soil profile into the ground water, affecting its acceptability as drinking water. To what extent the nitrates in water originate from agricultural or urban sources is not known nor the degree of improvement that would result from modified land management practices.

c. <u>Mineral and other inorganic substances</u> - The primary mineral contaminant of water of concern to agriculture is salt. Originating as a natural constituent through geologic processes, its concentration tends to be increased by irrigation. It has been treated as a separate subject in section 9 of this report. Other inorganic contaminants enter water streams as a consequence of mining operations and from chemical and metalurgical industrial processes. Some of these substances, such as sulfuric acid, greatly affect the usability of this water for agriculture as well as for other users.

d. Pesticides - The use of pesticides has given a tremendous assist to the efficiency of agricultural production and hence to the national economy. At the same time, it has introduced large quantities of pesticides into the environment that adversely affect the health and well-being of human beings and the welfare of fish, wildlife, and the natural environment. Between 40 and 50 percent of the dollar sales of pesticides in the U.S. and Canada are for use on lawns and gardens in towns and suburbia. In 1962, 15 million acres of urban land were treated with insecticides. If herbicides were included, the figure would be higher. Evidently, a significant part of the pesticide pollution problem is derived from nonagricultural uses. The transport of persistant pesticides by water into streams, lakes, and underground supplies is of concern to this Task Force.

e. Animal wastes - The tendency towards livestock production in confinement has resulted in an unprecedented concentration of animal wastes. Feedlots with 15,000 cattle and chicken houses with 40,000 broilers, frequently without adjacent lands suitable for disposal and fed products grown far from the point of consumption, cause an important disposal problem.

Economic forces make it mandatory that disposal schemes be kept down in cost. Yet the organic matter, the nutrients, and the pathogens that can and do enter into water supplies from these concentrations of animal waste pose dangers and economic losses that must be prevented or minimized. The development of better technology of waste disposal, be it by irrigation, by diversion of surface water, or by other means, is a most urgent need of high priority.

f. Processing wastes - Wastes associated with agricultural processing plants such as canneries, sugar refineries, chicken processing plants, and pulp and paper mills, pose problems similar to those of animal waste disposal. Here, too, the problems are urgent and the need for accelerated research a matter of high priority.

g. Sewage - Domestic sewage disposal and processing is not generally considered an agricultural problem. It affects agriculture, however, in two ways. First, the utilization of secondary treatment effluent for irrigation permits augmentation of water supplies for agriculture in areas of water shortage. Irrigation with sewage also provides a means of water purification that prevents or reduces the pollution of downstream water supplies. Secondly, the disposal of wastes from homes not served by a centralized sewage system causes problems in rural as well as suburban areas. Improperly operating disposal beds result in human health hazards and degradation of water quality at the expense of recreation and other beneficial uses, as well as in possible dangers to animal production.

h. Heat - The primary source of heat as a pollutant is cooling waters from industrial plants. The attendant rise in water temperature may adversely affect the fish population. Not considered in the Quality of the Environment report is the possibility of a significant increase in this type of pollution associated with the construction of a series of nuclear generating plants along a river, as planned for the Columbia River. The possibility exists of using the discharge water for irrigation, thus dissipating the extra heat energy prior to reentry of some of the water into the river.

Need for research

Except for the area of erosion and sedimentation, the realization of the importance of the interaction of agricultural water management with the quality of the environment is relatively recent. Increased sophistication in agricultural technology, an expanding population and greater affluence with associated stresses on recreational facilities, combine to focus attention on problems of water quality. At the same time economic returns to the farmer are relatively less, expensive control measures are becoming necessary. Much of the knowledge gained over the years--on fertilizer efficiency, erosion control, irrigation practices, and soil salinity, for example--has application to questions of pollution. Yet, often specific data or quantitative evaluations are lacking. Increased emphasis is needed in research to provide a framework for evaluating the effects of given agricultural management practices on the various quality aspects of water and to permit the development of recommendations that provide economic and effective control of unnecessary pollution.

There is an accelerating need to generate information on the economic implications of decisions, on alternative means of regulation, and the alternative adjustments possibilities for affected firms. The research must be based on an expanded knowledge of current control programs and those emerging under Federal, State, and local regulatory authorities and financial arrangements. This information on Government institutions should be supplemented by knowledge of the organization of firms and structure of relevant industries and markets. There is a critical need to develop a capability for more precise measurement of monetary and non-monetary quality attributes, and to assess the external economies and diseconomies and secondary economic effects of waste disposal systems and pollution control programs. For example, erosion and sediment control can enhance soil fertility, production response, increased income, and reduce operating costs, while at the same time satisfy the needs for recreation and aesthetics.

Objectives

In view of the report, "Quality of the Environment," it appears redundant to spell out here in detail the needs and approaches recommended for research dealing with water pollution. May the following brief statements suffice.

A. Delineate sources of pollution. In too many instances, statements are made without a basis in fact as to the origin of a pollutant. Quantitative studies are needed to evaluate the contribution of agricultural fertilizers to lakes, of dairy cattle to streams, of pesticides applied to cropland to rivers, etc.

B. Determine time distribution of pollutants. The problem of evaluating the agricultural contribution to pollution is complicated by the time variations in runoff and in concentrations of pollutants in the runoff. Are pesticides removed with runoff in uniform concentrations? Is the effect of land disposal of animal waste dependent on soil water content, on temperature and time of year? A quantitative evaluation of the pollution problem requires careful analysis of these time dependencies.

C. Devise means to reduce pollution from agricultural sources. Control measures must be developed that are physically sound and meet desired social and economic objectives. Whereas in certain instances such measures can be developed and tested now, in others it is necessary to first determine the extent and the nature of the problem as outlined under (A) and (B). But in all cases it is increasingly important that alternative means of control be evaluated to assure that they are in harmony with the productive use of our physical, biological, social, and economic resources.

D. Devise means to alleviate pollution through agricultural means. The possibility of utilizing more effectively than at present the cleansing ability of nature offers valuable opportunities for reducing pollution hazards. Liquid disposal of domestic, animal, and processing wastes by irrigation of agricultural or forested land is not a new idea but one insufficiently understood for more than sporadic application. Controlled sewage recharge to ground water also offers possibilities yet unexplored. Economic analysis of the costs associated with disposal compared to the benefits derived from the application should lead to criteria for evaluating the feasibility of such systems. Economic analysis and institutional studies would provide the basis for modification of existing and proposed regulation and enforcement arrangements to most effectively fulfill the objectives of quality while preserving other important goals and objectives.

Potential benefits

Research on maintaining and enhancing water quality is relevant to the needs of people and their social, economic, cultural, physical, and productive objectives. Precise measurement of benefits is not always possible. However, if we are to sustain human life at a higher level of living, we must improve our decision-making process. Research can enhance the productive uses of water and satisfy other needs such as recreation, aesthet

Evaluation of alternative means of maintaining and improving water quality provides a basis for communication and reconciliation among different groups. It also provides a basis for judging alternatives and for the selection of alternatives that will best satisfy desired social, cultural, and economic objectives. Economic analysis will identify options that secure maximum benefits through increased income or cost reduction, and identifies the penalties that must be imposed to secure non-monetary benefits. More rational arrangements can be initiated when strengths and weaknesses of institutions and regulations are exposed.

Present and projected research efforts

A rough estimate of present research activity in relation to water quality in agriculture is 285 SMY. This includes 122 SMY already referred to in sections 9 and 11 of this report. The level needed, in all areas other than those treated in sections 9 and 11 should be 275 SMY in 1972 and 390 SMY in 1977. These projections are in accordance with the Task Force report, "Quality of the Environment." A breakdown is provided in the following table.

Estimated current USDA, State agricultural experiment stations, and Cooperating Forestry School program of pollution research related to water and projected to FY 1977

Subject Area	SMY's Estimated current program	SMY's Projected for FY 1977
Animal and domestic wastes	18	94
Processing wastes	15	67
Plant nutrients	100	138
Mineral substances other than salt	18	39
Pesticides	10	20
Socioeconomic aspects	2	32
	163	390

XIII Developing Improved Economic and Institutional Arrangements

Situation

Our average annual supply of water amounts to about 30 inches of rainfall over the United States. About 70 percent of all rainfall is consumed on-site by vegetation and is returned to the atmosphere by evaporation or transpiration. The remaining 30 percent, about 1.3 billion acre-feet, reaches streams or ground water where it is available for withdrawal and use. About a fourth of this water is actually withdrawn for use; and about a third of all withdrawal is consumed in the sense of not being available for reuse.

Thus, our overall water supply is abundant. In some regions and localities, however, we are approaching full utilization, and in all parts of the country droughts create serious temporary deficiencies. At the other extreme are flooding and drainage problems caused by too much water. Local, State, and Federal funds are expended to meet the many objectives of water resources development, and procedures for determining optimum allocation of funds among individual projects or among regions are in need of improvement. Projects which satisfy local needs may not contribute to regional or national needs. Part of the problem stems from lack of understanding of the role of water resources in local, regional, and national economics, as well as from difficulty in identifying and evaluating intangible effects of projects. This prevents a determination of the total economic effects and the sociological impacts of individual water resource development projects. Because economic benefits are not well defined, problems arise in allocating costs equitably among project beneficiaries.

There are many kinds of institutions that deal with water. Statutory laws, court cases, constitutions, and administrative rules and practices are the most readily identifiable. In some instances they are structured and operated in ways that promote achievement of economic and social objectives for water use, while in other instances the reverse may be true. Research concerned with the institutions governing our water resources has principally sought to identify and define complex legal systems, but increased attention must be given to the economic and social impact of the laws and doctrines affecting water use and development. Some specific questions include: Are the systems too rigid? Are the systems in themselves archaic in regard to other social and economic institutions? Do the systems promote or prohibit efficient water use? The legal institutions affecting water resources are founded in other institutional factors, namely the habits, customs, and attitudes of people toward the use of water. Thus, research on the effects of various institutions on water use should include fundamental studies to fully identify habits, customs, attitudes, behavior, and the effect or interaction of them with technology on the structuring and operating of formal institutions.

Historically, water projects have been planned in the contex of single or only a few purposes. Most investigations relate to specific development proposals in small localities and basins. In recent years, water resource planners have emphasized comprehensive planning to include considerations of all purposes and beneficiaries. Comprehensive interagency water resources planning was greatly expanded by the Water Resources Planning Act of 1965, which provided for the establishment of river basin commissions. Their major function is broad planning and coordination of Federal, interstate, State, local, and nongovernmental agencies in their particular river basins. Four such commissions have already been established. No doubt, these commissions can play an important role in coordinating the planning of water resource problems; they also add to the complexity of the institutional framework for water resources planning, particularly where defined coordinating responsibilities conflict with the existing distribution of legal authority. In addition to the conflict over governmental authority, there are fundamental issues regarding conflicts between private property water laws and public-policy water laws. The growth of interagency planning mechanisms thus creates a need for new information on water resource management and development to identify needed improvements in administrative structures.

Plans for the conservation and management of water resources must take into consideration the water requirements of both rural communities and urban centers. Water supplies for these communities have their origin in the rains that fall on rural watersheds. Careful management of these watersheds is required if water yields, both surface and underground, are to be maintained or increased. Because of rising public service costs in urban communities it has become more important to manage watersheds efficiently and to minimize the costs of providing clean water.

In many States, water quality standards have been established without giving full consideration to the costs of pollution abatement. Some forms of pollution present such complex problems that it may not be possible for the industries affected to comply with the standards that have been adopted. Farmers and agriculture-related industries are influenced by these rules. Both the social costs and the social benefits of pollution abatement need to be taken into consideration when water quality standards are being developed. If it is not economically desirable for persons or businesses to comply with the standards, either the standards must be modified or special institutional arrangements must be created. There is a need for better information on the range of such arrangements available, how they might be applied, and the way in which they distribute the benefits and burdens of pollution abatement on affected parties. Programs relating to water quality control need to take into consideration the aims and objectives of related resource development programs.

People and industries in our economy today are highly mobile. The rapid rural to urban population shift of the past has contributed to the problems of our cities. The majority of our people are now in urban centers with only a small portion working or residing in rural areas. Pressures for environ-

mental improvement call for an examination of population distributions across the land. For example, information on the role of water supplies in designing optimum settlement patterns would be helpful. Economies also may be realized by developing methods of using water to improve the natural resources environment. With new uses and increased competition for water supplies, existing institutional arrangements will come under increased pressure and perhaps prove inadequate. Thus, accompanying studies of new patterms of use and demand for water should be an analysis of needed institutional adjustments.

Although there has been a gradual evolution of water policy over the years as a result of the constructive thinking of many public agencies and groups, there is today no comprehensive national economic policy governing the efficient use and development of water resources to best serve the needs of the people. There are few guidelines to throw light on social choices which must be made in water management--choices related to such outcomes as economic income, economic stability, economic distribution, and economic freedom. The outcomes that are realized evolve out of piecemeal decisions, and there is little assurance that the intended objectives of society are being improved. Increasing demands on the water resources of the Nation call for a comprehensive economic policy with constant scrutiny and revision to keep pace with the changing times. Economic research, <u>per se</u>, does not formulate policy or make policy decision, but it often does provide information that is valuable to policy-makers, and it can examine and analyze specific policy issues.

Need for research

Water resource economics and planning was declared by COWRR as a most promising area of research in terms of immediate and long-term payoff. This committee also described work in the planning area as the most neglected in the present research program.

Substantial efforts and resources are being applied in water resources planning. New forms of planning organizations often involve different levels of government, several subject-matter disciplines, and have complex responsibilities in planning for future investments. Continuing research is needed to improve planning techniques; particularly is there a need to devise methodology and identify data needs for economic and institutional research support. With greater attention to multiple purpose, the number of alternatives to be evaluated increases sharply, creating more complex analytic requirements. These analytic requirements also are complicated by the need to explicitly treat nonquantitative factors in planning, including institutional and behavioral factors.

Closely related to studies to improve planning techniques are those for improving evaluation processes. Benefit-cost analysis, developed for water resource project evaluation, continues to be the most widely used method of evaluation. But more complex and more diverse concepts of benefits and costs

are being set forth, improved methods of measurement and data processing facilities are available for analysts; and the objectives of water resource projects become more complex. Thus, there is urgent need for research to improve benefit-cost techniques and to develop new evaluation methods to satisfy current-day issues and capabilities in water resource development.

Studies also are needed to isolate the constraints on economic growth and development that arise from the legal-institutional structure affecting water resources, and to develop a basis for recommending needed changes. "Optimum" water resource plans must be more clearly defined in terms of the economic alternatives and in light of institutional constraints.

Considerable research is needed to develop techniques for efficient minimum cost design, construction, and operation at engineering works required to implement water resources programs. Needed is the development of operational systems designed to provide public decision-makers with the information they need to make informed judgments on water management questions.

Research also holds the key to an understanding of the impact of water pollution control legislation upon agricultural and other interests, together with appraisals of institutional and organizational arrangements for implementing such legislation and distributing resultant benefits and costs.

The matter of using water to improve the natural resource environment has not been researched in depth. Environmental policy goals have not been clearly defined and subjective feelings guide many actions in this field of endeavor. Research is needed to perfect a more objective approach to environmental quality problems, to integrate diverse efforts under a total systems approach, and to relate water to other components of the total ecological system. Information is particularly lacking in the area of individual perception of the real justification for water resource development and control. New approaches to the behavioral aspects of bringing water under closer economic management are needed--to more correctly anticipate sociological problems in implementing water resource programs and to forecast basic consumer demands for water services.

A basic requirement for meeting the research needs described is a readily available fund of data on water use and supply, including associated economic and institutional information. A portion of the total research effort should be committed to fulfilling these needs, including identification of data needs and deficiencies; developing efficient sources and means of collecting the collection itself; and, finally, maintaining data series where these are essential to long-term programs of research or water resources planning.

Research into the economic ramifications of alternatives of water policy is still in a state of infancy. For example, there is no body of supporting economic information similar to that which has been developed to guide the future of the agricultural industry. Such a body of information must be developed if water management is to directly relate to the welfare of people in society and a concerted effort is to be made to utilize water resources as efficiently as possible.

The management and rehabilitation of the Nation's watersheds will require major investments of capital and operating costs. Better identification of investment opportunities consequently can result in major savings of public funds and increased benefits to land and water users amounting to millions of dollars annually. Improved knowledge of the benefits and costs of alternative watershed programs is of direct assistance to all agencies, land managers, and groups concerned with the development of forests and related watersheds and the strengthening of rural communities.

Current research involves evaluation of the costs and benefits of different land treatment practices, or combinations of practices, to increase yields of water and other products obtainable from selected areas of watersheds. Most of this research is concentrated in the Southwest where water problems are becoming more and more critical.

Practices being evaluated include modification of timber cutting, land clearing, prescribed burning, chemical control of vegetation, planting with trees, shrubs, or grasses, and construction of water control facilities. In addition to determination of current and future costs, these studies include development of methods for measuring economic and social benefits in terms of on-site, regional, and national values.

There are many possible levels of watershed improvement and development; each with a differing cost-benefit relationship. This research is consequently designed to determine the relative costs and benefits of land treatments under varied conditions of cover, site, ownership, and land use. To this end computer techniques are being developed to permit rapid and efficient evaluation of numerous combinations of land treatments and land uses. Such information on alternatives is increasingly vital for efficient administration and economic development of watershed resources.

Objectives

A recommended program of research on economic and institutional aspects of water resources would be structured around the several broad areas of research which follow. Some specific research objectives given for each of the research areas are illustrative of the problems that should be analyzed.

A. Evaluation process

1. Develop improved methods for identifying, measuring, and evaluating benefits and costs of water resource projects and programs to include:

    a. Methods which give consideration to non-quantitative cost-utility analyses.
    b. Procedures for measuring externalities.
    c. Techniques for identifying beneficiaries, cost sources, and principal participants associated with works of improvement.
    d. Methods for comparing efficiencies of competing projects.

2. Adapt and apply benefit-cost analysis and other analytical techniques to evaluate new farm and forest water management technology.

B. External effects of water resource development

1. Analyze the primary and secondary impacts of water resource development on regional and national production.

2. Identify and measure the role of water resources in community and regional economic growth, including economic and sociological impacts.

3. Determine water resource supplies needed to complement economic development potentials.

C. Techniques for water resource planning and policy evaluation

1. Adapt and apply analytic research tools to comprehensive water resource planning for the purpose of simulating economic structural water resource planning areas and effect thereon of alternative water resource projects, including nonstructural alternatives.

2. Develop in cooperation with other research programs and action programs minimum cost plans for collection, storage, use and disposal of water for a range of water-supply systems including self-supply systems, rural and small community systems, urban systems, and special-purpose systems.

3. Develop and test criteria for design of a comprehensive water policy.

4. Incorporate analyses of water quality and aesthetic alternatives in comprehensive regional and community water resources development planning.

5. Develop economic models to parallel proposed hydrologic modeling of watersheds. The purpose of such studies would be to simulate production conditions under alternative watershed management approaches as a basis for predicting economic effectiveness and acceptability of proposed projects.

6. Conduct economic studies of alternatives to watershed structures, including institutional as well as land treatment and management alternatives. This work should be carried out in conjunction with research on the role of soils and vegetation in the hydrologic performance of watersheds.

7. Identify "onsite" and "offsite" effects of watershed structures and economic effects stemming therefrom.

8. Evaluate implications of alternative water resource plans for spatial, transportation, and other public facility requirements in community planning.

9. Develop and apply analytic techniques to identification and measurement of regional and interregional effects of planned multipurpose regional water resource development.

10. Analyze expected effect of alternative cost allocation and cost share arrangements upon rate and scale of development, including study of the sensitivity of variations in repayment methods and interest rate.

11. Evaluate organizational alternatives for allocating water between agriculture and other uses.

D. Legal and institutional aspects of water resource ownership, development, and use.

1. Determine through legal studies the extent and effect of constitutional and other statutory limitations on water use, including Federal, State, and local statutes, and intergovernmental operating arrangements.

2. Analyze individual and group perception of law and the resulting impact on resource management decisions.

3. Conduct continuing analyses of law pertaining to water property rights, land and water use regulations, and of organizations directly involved in water resource planning, development, and program administration.

4. Ascertain the effectiveness of such social controls as zoning, taxation, easements, and compensatory payments in different water resource management situations.

5. Evaluate economic and policy aspects of specific legislative actions, such as for water quality control, changes in basic water rights doctrines, and diversion of water within and between river basins.

6. Develop analytic models of the relation of organizational structure and processes to policy decision, and program planning, evaluation, and management.

E. Behavioral studies

1. Identify ways that individuals and groups perceive water resource problems, and the relation of these perceptions to the way in which water resource programs are being carried out.

2. Analyze the role and relative importance of informal arrangements and procedures in private water use and in community or regional water use management, transactions, and policies.

Potential benefits

Concern for the use, conservation, and development of water resource is relevant only as it pertains to the needs of people. The water research needs involving economic and institutional problems discussed herein will provide information relevant to society's concern about water. Precise measurement of expected benefits by society from economic and institutional research is impossible. The type and general nature of benefits may be identified, however. In this way, the relevance and importance of the work can be highlighted.

Improvements in evaluation processes will allow individuals and public bodies to make more rational economic decisions in developing and allocating water resources. Farmers and agricultural communities will be able to improve their income earnings through the adoption of new water management technology. Improved water management will allow products and services to be produced at reduced costs. Efficiencies gained will benefit consumers as well as producers. Improved management decisions also will complement the economic growth of a locality or community. Residents in areas of low income and regions of under-utilized resources will benefit from water economic research to improve their decisions on water development expenditures.

Research to improve techniques of planning and to improve planning institutions will help ensure that all purposes and uses of water are considered in the planning for water resource conservation and development. In this way the concerns and interests of all individuals and groups may be systematically related. For instance, the benefits and costs of water-based recreation development, water quality control, flood protection, and environmental programs may be studied in context. Improved planning procedures will assist those developing programs in providing water supplies to the various users consistent with the economic opportunities and social needs of communities. Improved procedures also will ensure that least-cost means of achieving water use objectives will be obtained. For example, nonstructural alternatives such as flood plain zoning may be appropriate as well as other less costly solutions to flooding problems.

Improved guidelines and procedures for making cost allocations among purposes and for sharing costs among beneficiaries will improve the economic use of water resources. Also, the guidelines will provide a more equitable distribution of cost between taxpayers and individual beneficiaries.

Legal-economic research to analyze water laws, administrative rules and other institutional arrangements will assist individuals and groups in decisions to modify these rules. Improvement in laws and administrative arrangements can be influential in the achievement of social goals. Moreover, a comprehensive

economic water policy for the Nation based on research will provide more consistent rational guides for water programs to benefit users of the Nation's water resources.

Present and projected research effort

Total SMY's for FY 1977 are shown in the tabulation below. SMY's projected for FY 1972 would amount to a doubling of the 1966 program. The higher rate of increase shown after 1972 would be possible as base staff needs are met for initiating work on major research problems and geographic locations for new work have been established.

Three-fourths of total increase is allocated to research needs and objectives set forth in this section; while one-fourth is allocated for economic studies carried out in support of soil and water research areas covered in other sections of the Task Force report.

USDA and State agricultural experiment stations staffing for FY 1972 is distributed in the same proportions as in 1966.

Proposed allocations of projected staffing increases for research on economic and institutional aspects of water management

	FY 1966 base (SMY's)	FY 1972 base (SMY's)	FY 1977 base (SMY's)
Allocation to Part 13 studies--economic and institutional aspects	NA	61	124
Allocation to economic studies, Parts 1-12, 14 and 15	NA	20	42
Total	41	81	166
Allocation to USDA	27	54	108
Allocation to SAES	14	27	58
Total	41	81	166

XIV Urban and Agricultural Water Interrelationships

Situation

As our population has grown and personal incomes have increased, the pressures on water resources have mounted. Demands for water continue to become greater for a wide variety of uses, resulting increasingly in real or apparent conflicts between agricultural and urban interests. At times, joint action serves all interests compatibly and profitably. There are examples of downstream flood control plans to protect industrial or municipal interests at the expense of upstream inundation of productive farmland; of recreational uses of reservoirs adversely affected by irrigation water use; and also of effective watershed development to enhance agricultural, municipal, and industrial development.

There are other interactions between agriculture and suburbia. Farmers can provide opportunities for fishing and hunting and increase their income; they may need to change their livestock management to reduce pollution of swimming facilities. The knowledge gained from agricultural research may be applied effectively to help solve problems of erosion from construction sites in cities and towns; municipal secondary effluent may be used for irrigation or groundwater recharge. The Little Talapoosa Watershed in Georgia and the Mountain Run Watershed in Virginia are good examples of effective programs of water resource development that benefitted agricultural interests, provided needed water for municipal use, and enabled industrial expansion. The programs to control sediment production from construction sites in suburban counties surrounding Washington illustrate the effective application of agricultural technology to the solution of a suburban problem. The Salton Sea in Southern California is fed primarily by agricultural drainage water; this water originates in the Colorado River from which it is diverted for irrigation. As the consequence of good irrigation management, the salt concentration of the Salton Sea continues to rise, endangering the recreational uses that have come into existence. Is a continued healthy agriculture to be preferred, or a lake suitable for swimming, fishing, and boating?

Many other examples could be quoted. The pertinent point is the need to recognize that, with increasing pressures on water resources and increasing contacts between rural and urban groups, it is necessary for agricultural specialists to concern themselves with the problems at this interface. Agricultural research scientists should do their part towards establishing guidelines for solutions to these problems.

Need for Research

Rural-urban contacts involving use of water resources have been increasing dramatically in both their variety and complexity. These contacts are not limited solely to the so-called rural-urban fringe. These interrelationships

usually have characteristics involving a variety of research disciplines. Such problems as water pollution or weather modification commonly involve physical, technical, economic, legal, social, political and even psychological aspects.

a. Recreational water use interrelationships

The study of outdoor recreational activity is relatively new and has been stimulated by surprising increases in demands on public and private recreation facilities. At present there is no reliable information on the quantity of recreation activity, by type and location, in rural areas except at some public facilities where accurate records are kept. There is no good basis for projecting recreational demands. A great need exists to develop basic data on the demand, supply, location, timing, and quality of recreation activities in rural areas. This information is specifically needed to properly plan, locate, design, and operate water resource projects, including recreation as a purpose.

The inclusion of recreation in multipurpose projects has resulted in a number of complex problems of competition. The use of a reservoir lake for recreation calls for a full reservoir in the summer months when the water is in demand elsewhere for uses such as irrigation, navigation, municipal supply, and low flow maintenance. A full reservoir has essentially no flood control capacity. Thus, in a timing sense, reservoir recreation often conflicts with other uses of water. There is a need for refined study procedures to evaluate and compare benefits and costs for various purposes. There is a need for hydrologic research to refine the information on which reservoir operating procedures are based. Is it necessary to draw down reservoirs for flood protection during the summer seasons? Can draw-down periods be altered to enhance recreational use?

There is need for economic, biological, and sociological studies on which to base regulation of recreation activities to minimize conflicts between recreating groups and to maintain the quality of the reservoir area. Serious erosion, deterioration of water quality, public safety standards, and aesthetic values may result from inadequate design and maintenance. Research is needed on the use of plant materials for heavily used recreation areas and to enhance and protect from erosion areas exposed during draw-down periods. There is a need for studies to develop efficient methods of controlling and removing sediment in reservoirs. There is a need for biological studies of reservoir fisheries and wildlife in adjacent areas in order to properly manage these resources and to properly regulate recreation use to enhance recreation activities based on these resources.

Maintaining high reservoir levels for reservoir-associated recreation may conflict with other recreation activity on downstream segments. There is need for research in several disciplines to develop information on managing downstream areas to enhance recreation opportunities. These problems

include maintenance of low flows and meeting quality standards including bacterial purity, dissolved oxygen, turbidity, and temperature. Complex decisions need to be made with respect to public health, optimum fishery environment and meeting recreation demands. A simple example is the decision on mixing reservoir releases which could create water temperatures for a good trout fishery or a good swimming facility.

b. Urban-industrial water use interrelationships

There are a variety of known interrelationships between urban-industrial uses of water and other uses in rural areas. There are other relationships that either are imperfectly known or can be expected to become manifest in the near future due to changing locational patterns, technology, or simply due to time lags.

Downstream agricultural water users may face changes in quality and quantity of supplies due to upstream urban or industrial uses. These changes may be beneficial or adverse. The adverse effects of harsh pollutants such as industrial acids or petroleum spillages are comparatively obvious. But the more subtle effects of municipal softing treatments, by adding sodium salts, or the increase in nitrate and phosphates from sewage effluent and detergent use are not well known. There is also need for research on storm water runoff in urban areas including quality aspects, such as infectious agents and fertilizer, pesticides and other chemicals.

Construction, compaction, and paving in urbanizing areas lead to reduction of infiltration capacities, concentration of runoff peaks and heavy sediment movement, at least initially. These urban hydrology changes need to be analyszed in terms of potential downstream effects on rural water users.

There are potential opportunities to exploit municipal and industrial effluents for beneficial use. While it is commonly accepted that municipal use is largely nonconsumptive, the presence of the majority of our large metropolitan areas on the sea coasts means that a large proportion of municipal effluent is now unavailable for reuse. There is need for additional research to assess the physical, technical, and economic potentials for reusing effluent waters for agricultural, groundwater recharge, recreation, and other uses. There is also a need for research to explore the possibilities for using industrial cooling waters for similar purposes. Both effluent and cooling waters appear to offer potentials through reuse to remove nutrient, salt, and heat pollution before return to natural stream or marine environments.

c. Agricultural water use interrelationships

The influence of agricultural and forestry management on water quality and quantity is of increasing public concern. The transmission links from diffused pollution sources on the land to points of effect down-

stream are imperfectly understood. Land and water management practices can have a profound effect on downstream water quantity. The management of snowpacks through forestry practices, for example, is of direct interest to urban-industrial users as well as to irrigators.

A much greater research effort is needed in the area of water quality management in rural areas. Heavy emphasis is required on physical and biological aspects. However, other disciplines must also be given increased emphasis. The present tendency is for pollution control agencies to treat agricultural firms similarly with industrial firms under their regulatory authorities. It is important to agricultural producers and the general public that additional technical, economic, and legal information be developed. These results are needed for progressive refinement in the regulation of agricultural pollution sources in order to achieve satisfactory control at minimum cost to affected producers.

There is need to further explore the relationships between agricultural water management and fish and wildlife abundance. Controversies over drainage of wetlands are well known although the essential technical or economic interrelationships are not well established. The installation of farm and stock water ponds is believed to have had a widespread beneficial effect on a wide variety of wildlife species. There are also abundant low-cost opportunities to flood areas of cropland during the dormant season with promising wildlife benefits, and possibly enhanced incomes to rural residents from hunters and other recreationists. These and similar relationships should be established through research.

d. Water resources and economic growth interrelationships

It is commonly accepted that the development of water resources--irrigation, navigation, flood control, drainage, hydro-power, and water supply projects--have played an important role in the historical development of the economy. It has also been established that abundant water resources do not in themselves guarantee economic growth. Nevertheless, the provision of water supply, management of flood plains, creation of recreation reservoirs, and intensification of the agricultural base through irrigation are activities that can influence the location, density, direction, and growth rate of population centers. The 1968 Housing and Urban Development Act authorizes a flood and flood plain management program; the creation of new towns in rural areas; and HUD--USDA coordinated planning assistance to rural development districts. There is an urgent need for research to identify and measure the influence of water development and use within the broader context of economic development and natural resources management in rural areas.

Millions of urban families have acquired second homes for recreational use in rural areas. Scores of developments featuring water-based recreation are now under construction. Properly planned developments can be expected to enhance incomes and tax revenues in rural areas. Improperly planned

communities will bring adverse economic and social impacts and deterioration in the quality of scenic and water resources. In many rural areas, increased productivity and alternative employment opportunities have reduced population density. The remaining population is consolidating to obtain increased quantities and qualities of social services including recreation, shopping, and medical facilities and improved educational opportunities at acceptable costs. Water resource developments, e.g., water supply and sewage systems, that inhibit desirable trends toward optimum population concentration would be ill conceived. Technical, economic, and social research directed at the broader questions of the interrelationships of water resources and economic growth is urgently needed to avoid costly mistakes in future water resources development in rural areas.

Objectives

Classification of research needs involving interrelations of water resource use by its nature must be somewhat arbitrary. The following categories represent one possibility. The specific research topics proposed illustrate the problems that require additional research information.

A. Recreational water use interrelationships.

1. Comprehensive data on the demand, supply, location, timing and quality characteristics of water-based and water-associated recreational activities in rural areas.
2. Identification and quantification of the physical, biological, and economic relationships between recreation and other purposes in the design and operation of multiple-purpose reservoirs.
3. Identification and quantification of the physical, biological, sociological, and economic relationships among various recreationist activities in order to design and manage recreation programs that minimize conflicts and accommodate a variety of activities while maintaining and enhancing the physical and esthetic resources of the reservoir and adjacent land areas.
4. New plant materials for use in enhancing and protecting heavily used recreation facilities and exposed reservoir areas. Continue and expand research in the safe and efficient control of water weeds.
5. Biological studies of reservoir fisheries and related wildlife to enhance recreation potentials.
6. Multidisciplinary studies of reservoir operation and downstream recreational uses.
7. Studies of economic and sociological impacts of urban recreation use of water-based recreation facilities in rural areas.

B. Urban-industrial water use interrelationships.

1. Physical, biological, and economic studies of the impact of urban-industrial water pollutants including storm water runoff on subsequent agricultural water uses.

2. Studies of the hydrological effects of urban, industrial, and highway construction on subsequent water users.
3. Studies of the physical, technical, and economic potentials for using municipal effluents and industrial cooling waters for beneficial uses in rural areas.

C. Agricultural water use interrelationships.

1. Studies of the influences of farming, ranching, and forestry practices on the quantity and timing of runoff and percolating waters.
2. Studies of physical and biological relationships between potential agricultural and forestry pollutants, such as animal and plant wastes, sediment, dissolved salts, plant nutrients, organic chemicals, infectious agents and weeds, and changes in the quality of water supplies for subsequent uses.
3. Economic and legal studies of agricultural and forestry pollution and alternative means of alleviation to achieve acceptable standards of water quality with minimum economic burdens on producers and minimum disruption of rural economies.
4. Multidisciplinary studies of agricultural water management and fish and wildlife resources to establish beneficial and adverse relationships and to explore potentials for complementary programs.

D. Water resources and economic growth interrelationships.

1. Explore the role of water resources development in stimulating economic growth and guiding patterns of population and production location under various conditions of local and regional development.
2. Assess the economic and social impacts of various water development projects on communities in rural areas, including impacts on the provision and financing of acceptable levels of public services.

Potential benefits

Resolution of conflicts and realization of potential complementarities in water resources use by various groups generally involves public planning, decision, and action. The effectiveness of public or group action in the complex situations discussed is heavily dependent on the information available to the decision makers. Benefits from the proposed research will be expressed in more effective public decision making resulting in more efficient communities, more efficient production and distribution, and greater consumer and citizen satisfaction from development and use of water resources.

Present and projected research effort

Proposed allocation of projected staffing increases for research on urban and agricultural water interrelationships is as follows:

	1966	1972	1977
SMY's	--	20	40

XV Synthesizing Research Efforts Through Systems Analysis

Situation

Water resources development is related to other national development needs and should be viewed as a complete system covering the many uses for which we employ water--domestic, industrial, waste disposal, agriculture, natural beauty, forests, wildlife, fisheries, and transportation. The planners and designers of water resource management systems must often choose among a number of alternative plans for the location and design of structures, land and water management systems, and institutional arrangements for effecting the acceptable plan. They must select some point in the continuum of possible degree of control and proceed with a plan in order to continue with the design or construction phase. Much of the research and analysis applicable to these systems has dealt only with bits and pieces of the system. Lack of adequate data and the laboriousness of methods of analysis have often severely limited the number of alternatives that could be compared and also prohibited a clear choice among a set of alternatives.

In our preoccupation with identifying the weak link in the broad and complex systems of water management, we sometimes fail to consider that adoption of a slight change may cause undue stress elsewhere in the entire system. Too frequently, our approach to problem solving is to accept the problem as it exists and work directly toward a solution. This can be a too narrow process and may lead to a workable but still unsatisfactory solution. We allow our conventional concepts to guide us. Instead, we should turn our attention more to an analysis of the problem itself to determine whether it can be broken down into component parts. We should consider the possibility that the end of a problem may come through the development of new means.

Systems analysis is a tool that can permit a view of the entire problem. It takes into account means and ends, choices and alternatives. It makes use of prediction and advanced testing to suggest objectives and course of action. It provides a method for more thorough consideration of alternatives. A likely first consequence of systems analysis is a restructuring of the problem itself.

Systems analysis may be viewed as a formalization of interactions. It contains few new concepts; it makes use of newly developed tools. Its application to water resources research is by no means restricted to the planning of large-scale water resource management schemes. It has an important role to play in increasing the effectiveness of research wherever large volumes of data and many interacting parameters are involved.

The development of better data, together with the development of high-speed computers, and the availability of newer analytical techniques have opened the way to more comprehensive analyses of relevant alternatives in the design of water management systems and the benefits which can be derived from those systems. Several professions are currently using techniques which are especially valuable where the system is so large as to defy analysis except with the aid of automatic data processing facilities, remote sensing, and data acquisition. For example, CPM (Critical Path Method), PERT (Program Evaluation and Review Technique), Monte Carlo methods, model sampling, simulation devices, and gaming are useful techniques.

Research objectives for water management systems are interrelated though not necessarily of equal priority. Some offer promise of immediate results. Some offer promise of greater returns. Some research is directed toward more urgent problems. Some research objectives are important because without their completion, other important areas cannot be fully developed. The simulation phases of systems analysis permit experimentation with systems that in reality do not exist and are too expensive to actually build and study. Ideally, research should be programmed so that problems are anticipated, investigated, and at least partially solved or even prevented before they are upon us.

Need for research

Research should anticipate future problems and aim for solutions before the problems become serious as well as attempt to solve problems we can readily foresee or are immediately serious. It should aim to reduce costs and increase benefits of water management and of water management research. It must include mechanisms to deal with ideas that are "far out" for these may be the important concepts of the future. Research should seek to protect us from mistakes.

We need an overall "systems" look at the problems indicated in this report and others related to water management systems on watersheds and river basins. Such a look requires sufficient data for thorough consideration of alternatives from the benefit-cost viewpoint, from an aesthetic viewpoint, from the quality of the environment viewpoint, from legal and social viewpoints.

The potential results of such a system (although initially it may be only a concept) are many. It may permit social and political predictions and forecast methodologies of the future. It will identify areas or subsystems needing research, subsystems which are sufficiently researched in relation to the rest of the subsystems and for which research may be reduced, and will provide opportunities for identifying new alternatives in the arrangement and sequencing of subsystems. It also can identify pertinent relationships within a subsystem, providing more adequate data evaluation and guides for more effective research approaches and techniques.

Research described in this chapter should be limited to the development of models and their use. Input data for decision making with the models should be provided from the research indicated in other parts of this report and from other related Task Force reports. Facility needs are primarily a high-capacity, high-speed computer. The challenge lies in finding the scientific competence, combining a strong interest in resource use with a basic knowledge of the principles of hydraulics, hydrology, soil science, biology, and engineering; and capability in computer technology, current analysis techniques, and systems theory.

The relative feasibility of accomplishing the desired result at reasonable cost should be ascertained at each step in the research, development, and demonstration process using whatever data are available.

Objectives

A. To develop analytical models characterizing the relationships between physical, chemical, biological, and social variables involved in water management and use.

B. To use such models in testing the outcomes of alternative approaches, assumptions, and inputs in the use and management of water.

C. To provide feedback between systems analysis and research approaches.

D. Use the models to predict performance, benefits, costs, and other measures of the relative success of viable alternatives in water management plans.

Potential benefits

The ultimate potential benefits of using systems analysis for water and watersheds is difficult to assess. A relatively small investment can result in savings in unnecessary research, in increasing the return from research, in savings in costs of water management plans, in added benefits from improved plans, and in savings through anticipation, prediction, and solution of problems in advance of their occurrence.

Present and projected research effort

Present research effort in systems analysis as described in this chapter is estimated to be non-existent. To achieve the objectives indicated 10 SMY are needed in 1972 and 20 SMY in 1977.